ELEMENTS OF PHYSIOLOGY

HOUGH
SEDGWICK AND WADDELL

** Zymogen is one of a Physiolgical group of globular bacteria which produce enzymes

~~Joe Sweet~~ Ines. Blood
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Monday

Chap 7 - Send 6 pages

Thurs - Finish chap ~~III~~ know it
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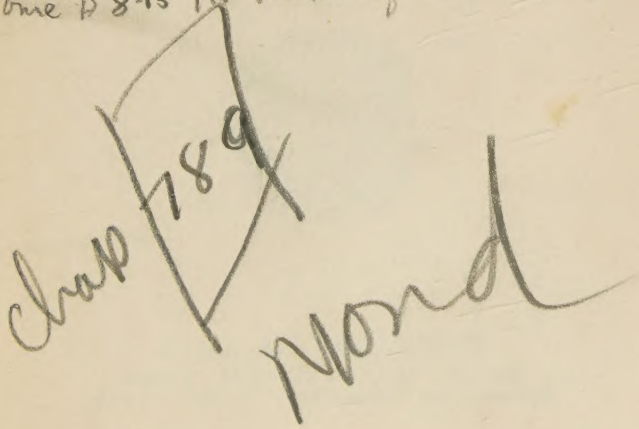

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ELEMENTS OF PHYSIOLOGY

BEING PART I OF "THE HUMAN MECHANISM, ITS PHYSIOLOGY AND HYGIENE AND THE SANITATION OF ITS SURROUNDINGS"

BY

THEODORE HOUGH

AND

WILLIAM T. SEDGWICK

SECOND REVISED EDITION

BY

J. A. WADDELL, M.D.

PROFESSOR OF PHARMACOLOGY AND FORMERLY ACTING PROFESSOR OF PHYSIOLOGY
DEPARTMENT OF MEDICINE, UNIVERSITY OF VIRGINIA; FORMERLY
EPIDEMIOLOGIST, VIRGINIA STATE DEPARTMENT OF HEALTH

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PREFACE

Health and efficiency are topics which vitally concern us all, individually and collectively. No person handicapped by poor physique can be fully productive; no nation ravaged by disease can be truly great. Experience has taught us, fortunately, that lack of health and want of efficiency are preventable, in large measure, by taking proper care of our bodies.

That one may care for his body properly, it is essential for him to understand its construction, the operation of its various parts, and its requirements for maintenance. This volume on the elements of physiology is designed to supply this knowledge by presenting in nontechnical language the fundamental facts and principles governing these matters, so that they may be readily comprehended by the average reader. To this end the human body has been likened to a machine and compared, as to its fundamental activities and maintenance, with the operation and upkeep of delicate machinery.

This edition of *Elements of Physiology* presents a thorough revision, in which have been incorporated those advances in science which are directly applicable to the purposes of the book. Advantage has been taken of the opportunity offered by the resetting of the whole text to make many changes in the interest of greater simplicity and clearness of presentation. Portions of certain chapters have been entirely rewritten — notably those dealing with the internal secretions, nutrition (including the vitamins), circulation and respiration, organs of special sense, and habit-forming drugs.

In this work anatomy has been reduced to a minimum. Space has thus been gained for a fuller treatment of physiology. Especial emphasis has been placed upon (1) the fundamental activities of the body, (2) the sources of the energy required for its operation, (3) the mechanisms for coördinating the different organs, (4) the sensations and the organs of special sense, and (5) the regulation of the body temperature. That form of physiology which looks chiefly at the organs and overlooks the organism has been scrupulously avoided; the attention of the student is constantly directed toward the body as a whole, in order that he may find therein the interpretation of the common phenomena of daily life and the logical basis for right conduct in living.

The index has been prepared with special reference to its use as a glossary. Careful attention has been given to cross references.

Elements of Physiology constitutes Part I of the second revised edition of *The Human Mechanism*, with the addition of a chapter on tobacco, alcohol, and other habit-forming drugs. Part II of the same book is also published as a separate volume, entitled *Elements of Hygiene and Sanitation*. The references to Part II have been retained in Part I and apply either to *The Human Mechanism* or to *Elements of Hygiene and Sanitation*.

Acknowledgments for assistance in preparing the manuscripts for previous editions and for this revision have been given in full in the preface to *The Human Mechanism*.

J. A. WADDELL

MEDICAL SCHOOL
UNIVERSITY OF VIRGINIA

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THE HUMAN MECHANISM

PART I. ELEMENTS OF PHYSIOLOGY

CHAPTER I

INTRODUCTORY. THE HUMAN MECHANISM

The ultimate aim of this book is to teach hygiene, which treats of the care of our bodies to the end that we may be more healthy and longer-lived, and thereby more productive and happy. It is a study to be pursued particularly by young persons, for it is during the period of growth and development that the abuses and negligences which engender ill health in later years have their beginning. In this matter the old adage is particularly applicable, "The child is father of the man," for it is in youth that we develop that vigor and stability so necessary to produce hale and hearty bodies for middle and later life. Furthermore, if we learn how to care for our bodies in youth, the habit or practice of observing health rules grows as we grow and becomes a part of our daily lives, for habits are self-perpetuating. If, on the other hand, we do not begin early, either damage may be done before the dangers are understood and avoided or, since we are not able to "teach an old dog new tricks," it may be impossible to break away from bad practices and to adhere to those principles so necessary for health and longevity.

One could not be expected intelligently to use and take care of a thing about which he is utterly ignorant. Even so simple an implement as a pencil requires a certain amount of knowledge as to sharpening to a point and holding in the hand. The more complicated the instrument, the more intimate must be the information about it. The chauffeur must understand his car, and the radio operator his appa-

ratus, in order skillfully to manage it and keep it in repair. So in the case of the human body; before we can learn to take proper care of it we must make a thorough study of its composition, its structure, and its essential parts,— learn why it is composed of certain materials and why these are put together in a certain way; what each part is for and what it contributes to the operation of every other part and to the maintenance of the body as a whole. Having acquired this knowledge, we shall then be prepared to find out what is needed to sustain the body and how it is to be supplied; what may injure the body and how it is to be avoided; and what will promote health and how it is to be attained.

1. The state of the body; life. The most remarkable thing in nature is the phenomenon called life, or the state of being alive. In the world about us we meet with two kinds of objects, the living and the lifeless. The latter is exemplified by a bit of stone; the former by our bodies and the bodies of animals. The members of these two groups exhibit fundamental differences which are embodied in the words "life" and "lifeless." Intuitively we distinguish between them, and in so doing apply subconsciously some or all of the attributes of life. We know that the stone is lifeless because it cannot move itself, breathe, increase in size, respond to the prick of a pin, or multiply its kind as do the insects and animals.

What the vital principle is,— what constitutes life and living,— no one can tell exactly. About all we know has been referred to above; that is, our bodies are living things which breathe and move, have marvelous powers for growth, repair, and reproduction, and in addition possess a certain spontaneity, originality, and independence which lifeless matter never displays. The motor car may be ever so expensive and complete in its equipment, but, like the stone, it always lacks what characterizes the living. It can develop

motion only when some force is applied from without; it cannot guide itself or oil itself; the taxicab will not grow to be a bus, though we may earnestly desire such at times. With the living it is different. The child, from the instant of its birth, moves and breathes spontaneously, as a result of the operation of some force from within its body; when hurt it responds by crying or moving its limbs; it knows when it is hungry, and seeks food; it grows in stature, initiative, and independence, finally making a home for itself and rearing a family.

2. The composition of the body. Our bodies are composed, for the greater part, of the most common *chemical elements*,[1] such as oxygen, hydrogen, nitrogen, sodium, potassium, calcium, iron, carbon, sulphur, and phosphorus. These are united to produce both simple and complex compounds. Among the former there may be found common substances like water, ordinary salt, cooking soda, and limestone; among the latter, fats like lard, proteins similar to egg white, and carbohydrates resembling sugar. Approximately 85 per cent of the human body is ordinary water, and another 5 per cent to 10 per cent is mineral matter. Though its chief constituents are simple materials, the substances formed from them are too wonderful on the whole to be imitated by human skill, in spite of our tremendous scientific advances. In them is incorporated that mysterious force called life — life with its powers of growth and action — life with its sacrifices and memories and loves.

3. The structure of the body; an organism. The human body is constructed of different parts, such as the head, trunk, and limbs. Each of these in turn is composed of lesser

[1] *Chemical element.* Water may be decomposed into the simple substances hydrogen and oxygen; neither of them can be decomposed further, and hence hydrogen and oxygen are elementary substances, or *elements.* Only ninety elements are known; from these few are formed the thousands of substances found in our universe.

parts: the eyes, ears, brain; the heart, lungs, stomach, kidneys; the hands, feet, fingers, and toes. The body is covered with the skin; scattered over its surface are hairs; the ends of the fingers are supplied with nails. Through the skin may be seen the veins, which appear as bluish streaks or ridges. Beneath the soft parts (flesh) may be felt the bones, which give to the body its rigidity and in large measure its shape. All these various parts are known as organs, each of which has a special part to play in the life and welfare of the body. Because the body is made up of, or possesses, organs, it is called an organism.

Similarly, the bodies of animals and insects, consisting like ours of organs, may be called organisms. On the other hand, a watch, because it has unlike parts (spring, dial, wheels, and case, which are essentially its organs, might be called an organism, but it never is so designated. We speak of a well-organized army, navy, government, society, church, or school, but never of a well-organized automobile, typewriter, or radio, apparently for the reason that in an army, navy, or school, living things play a principal part, while in mere machinery life is wholly wanting.

4. Machine; mechanism. Machines are such common things in our lives that it seems hardly necessary to define or explain what is meant by the term. We have ridden in automobiles and have manipulated the dials of the radio. We have observed that each consists of many parts, the former consisting of engine, gas tank, starter, generator, and so forth, and the latter consisting of antenna, switch, vacuum tubes, loud speaker, and so forth.

We may define a machine as an object or contrivance, constructed of few or many parts, and designed to serve some useful or desirable purpose. The automobile is an extremely complex example. In every case, whether the parts be few or many, each must be adapted and coördinated with

other parts. By analogy the human body may be called a machine. It is the most wonderful of all machines — a complicated assembly of parts, which are interdependent and coördinated to the uttermost nicety so as to produce from the stored-up power of foods the heat required to maintain the body temperature and the energy required for muscular, nervous, and other activities.

A delicate and intricate machine is often called a mechanism. A radio "set," with its transformers, condensers, rheostats, switches, and tubes, is a mechanism; a more complex example is the "Product Integraph," recently developed at the Massachusetts Institute of Technology, a "mechanical mind," constructed of motors, wheels, levers, wires, and switches, and able to solve mathematical problems in an almost superhuman manner.

5. The human mechanism. We have noted that the human body may be likened to a machine and that delicate machines are called mechanisms. Accordingly, it will be appropriate in a mechanical age like ours to refer to the human body as the *human mechanism* and to compare its operation with that of other but far less complicated machines.

All machines, in order that they may fulfill the purpose for which they were designed, require maintenance and care in their operation and use. The automobile must be supplied with gasoline, oil, water, and air, its bearings and brakes must be adjusted from time to time, its engine must be protected against extremes of temperature, and it must be skillfully steered to avoid traffic accidents; the radio must be supplied with electricity from a battery or from the house current through a rectifier, its switches and rheostats must be kept in adjustment, and it must be protected during thunderstorms by a lightning arrester. The more delicate the mechanism, the greater its need for attention and the greater its danger from neglect.

6. The maintenance of the human mechanism. We must be mindful that the human mechanism is a living organism, and that, as such, it is endowed with all the attributes of life — motion, respiration, growth, responsiveness, and repair — and, in addition, originality and independence. Like the lifeless machine, it requires certain essentials for its operation and maintenance in a state of efficiency: (1) a suitable environment, equitable in temperature and moisture, flooded with fresh air and sunshine, and filled with interests and friends; (2) an ample supply of food, wholesome in quality and sufficient in variety to provide for growth, repair, and activity; (3) a careful mode of living, proper distribution of time among work, recreation, and sleep, correct habits as to eating and bathing, and common sense in the matter of clothes and shoes; and (4) a scrupulous avoidance of abuse, extreme exhaustion, sudden changes in temperature, self-medication, failure to secure treatment for physical defects, and exposure to communicable diseases. These are, in brief, the essentials for the preservation of the health of the body, and for the maintenance of that vigor so necessary for the accomplishment of our daily work — our daily work, in which alone is to be found the *summum bonum*!

CHAPTER II

THE STRUCTURE OF THE HUMAN MECHANISM: ANATOMY

The study or the science of the construction (structure) of the human mechanism is called its *anatomy*; of its ordinary behavior, operation, or working, its *physiology*; of its proper management, protection, and care, its *hygiene*. This textbook is devoted chiefly to an account of its operation and care, that is, to its physiology and hygiene; but as any true comprehension of these subjects depends upon some preliminary knowledge of the parts of the mechanism itself, we shall begin by considering briefly the structure or anatomy of the human machine.

I. Definitions and Explanations

Function, as employed in physiology, refers to the specific acts performed or service rendered by a part of the body; for example, the function of the muscles is to produce motion, and that of the feet is to carry the body.

Protoplasm is the material of which all living matter is composed. It contains many of the chemical elements (p. 5), united to form complex compounds.

Cell is the term used to designate the fundamental structural unit of the body. It consists of a minute portion of protoplasm, called cytoplasm, containing a kernel, the *nucleus* (see Fig. 1). The latter may be said to be the brain of the cell, since all the cell's activities are directed from this point. Many different kinds of cells are necessary to

the body; for instance, the cells of glands, muscle, liver, bone, etc. Diagrams of some of the various types are shown in Figs. 1, 23, 24, 28, 29, and 33.

Tissue is composed of cells bound together with adhesive and fibrous materials. Tissue differs according to the part of the body in which it is found and the use made of it; thus, we speak of liver tissue, brain tissue, connective tissue, etc.

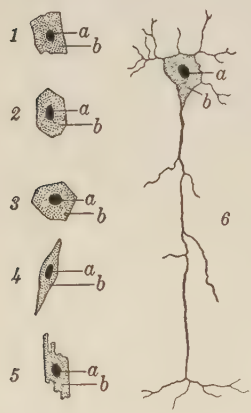


FIG. 1. Diagrams of several kinds of cells

a, nucleus; *b*, cytoplasm. *1*, gland; *2*, bone; *3*, skin; *4*, intestine; *5*, heart; *6*, brain

Organ is the name given to a part of the body having a characteristic shape and performing a definite function; for instance, the eye for seeing, the kidney for secreting urine, the heart for pumping blood, etc. An organ is composed of tissues of several kinds which in turn are formed of cells of various types.

Anterior, *posterior*, *dorsal*, and *ventral* are terms employed to indicate the position of one part of the body in respect to another. The first two are used to indicate closer to and farther from the head; dorsal and ventral, toward the back and front, respectively. A few illustrations will make the usage clear: the shoulders are anterior to the hips, while the hips are posterior to the shoulders; the knees are ventral to the heels, while the heels are dorsal to the knees.

II. The Gross Anatomy of the Body

Anatomy is studied partly by *dissection*, which reveals chiefly those organs which are visible to the naked eye, and partly by *microscopic examination*, which gives a deeper

insight into the detailed arrangement of the cells and tissues of which the organs of the mechanism are composed. The present chapter is devoted to structures or organs shown by dissection — the *gross anatomy* of the body — as distinguished from its *microscopic anatomy* (*histology*).[1]

1. The skin. The body is everywhere covered by a complex protective and sensitive organ, the skin. Only the eyes and nails seem to be exceptions; but as a matter of fact the exposed surface of the eye is covered by a very thin, transparent portion of the skin, and the nails are really modified portions of skin.

2. Subcutaneous connective tissue. On cutting through the skin we find that it is bound to the underlying flesh (chiefly *meat* or *muscle*) by what is known as *connective tissue*, the structure of which we shall study in the next chapter. Meanwhile we may notice that it contains blood vessels, that at some places it is more easily stretched than at others, and that when a flap of skin is pulled away from the muscles, this subcutaneous tissue fills with air. It often contains large quantities of fat (Fig. 2).

3. Muscles and deeper connective tissues.[2] The subcutaneous connective tissue sometimes connects or binds the

[1] Further explanation of the structure of the human machine will be given as may be needed in subsequent chapters. At this point it is of the utmost importance that the student thoroughly master the general relations of the more essential organs one to another; this, however, is not to be done by extensive reading, and still less by memorizing verbal descriptions; the aim should rather be to acquire from *figures and diagrams*, or better yet from *actual dissection*, where that is possible, a correct mental picture of the structures involved. Far more can be learned by constructing drawings or diagrams from memory than by the mere memorizing of text. The drawings may lack finish and may be at first difficult to execute; but so long as they represent the relations of the organs one to another they accomplish their purpose; beyond this point the more accurately they are drawn the better.

[2] The general appearance and arrangement of muscles, their attachment by means of tendons to bones, and the action of tendons on bones can be beautifully shown by a dissection of the leg of a chicken. The difference between trunk and limbs in the matter of the body cavity may also be readily demonstrated on the same animal.

skin directly to bone, as in parts of the head; usually, however, in the neck, trunk, and limbs the underlying tissue is the red flesh, or *muscle*, familiar to us as "lean of meat." If the skin be removed from the forearm, it at once becomes evident that this mass of meat or flesh is composed of a number of muscles which may be separated from one another more or less completely. In doing this it will be found that the muscles are held together by connective tissue in most respects quite similar to that immediately under the skin. Further dissection will show that one or another form of this tissue is the means of binding other organs together; thus the muscles are joined to the bones by a very dense, compact, and strong form known as *tendon*; the bones are united by a somewhat similar form known as *ligament*; and so on. The physical characters of the tissue differ widely, according to its situation and use; but one form shades more or less into another, and we have no difficulty in recognizing the general similarity which leads us to group them all together in one class.

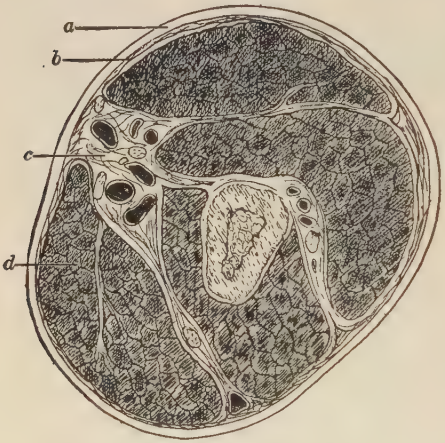


FIG. 2. Cross section of arm

a, skin; *b*, subcutaneous connective tissue, binding the skin to the muscles *d*, and continuous with the connective tissue which binds together the muscles; *c*, blood vessels and nerves

4. Muscles attached to bones. When a muscle is carefully dissected away from neighboring muscles and other organs, it is almost always found that it is attached to one and usu-

ally to two bones; this union is frequently made by means of a *tendon*, as in the case of the large muscle of the calf of the leg, which is attached at one end to the bone of the thigh and at the other to that of the heel. A good example of the direct attachment of muscles to bones is furnished by those muscles which lie between the ribs (see plate facing page 16). In either case the shortening of the muscle brings closer together the bones to which it is attached (Fig. 25).

5. The body cavities.[1] There is one striking and important structural difference between the trunk and the limbs; the former contains a central body cavity, completely filled, however, with various organs, while the arms and legs are each composed of a continuous mass of tissues, namely, muscle, blood vessels, nerves, bone, and so on, all bound together by connective tissue (Figs. 2 and 3).

The cavity of the trunk, or body cavity, is subdivided transversely by the dome-shaped muscle known as the *diaphragm* into two cavities: an anterior, known as the *thoracic*, or *pleural, cavity*; and a posterior, known as the *abdominal*, or *peritoneal, cavity*. Both cavities are lined by a smooth, thin, shiny membrane, that of the thoracic being known as the *pleura*, and that of the abdominal as the *peritoneum*.

Filling the pleural cavity are found the *heart*, *lungs*, *esophagus*, *windpipe* (or *trachea*), and many great *blood vessels*; filling the abdominal cavity, the *stomach*, the *small intestine*, the *large intestine*, the *liver*, the *pancreas*, the *kidneys*, the *spleen*, and other organs, together with numerous large and important *arteries* and *veins*. In both cavities the lining membrane (pleura or peritoneum) is folded back over the organs, just as a rubber balloon would be folded over the hand if one wall of the balloon were pushed in against the other. The

[1] "Cavity," as employed in anatomy, does not mean an empty space; it is a portion of the body filled with organs and walled off from other portions by bone, or muscle, or both of these tissues.

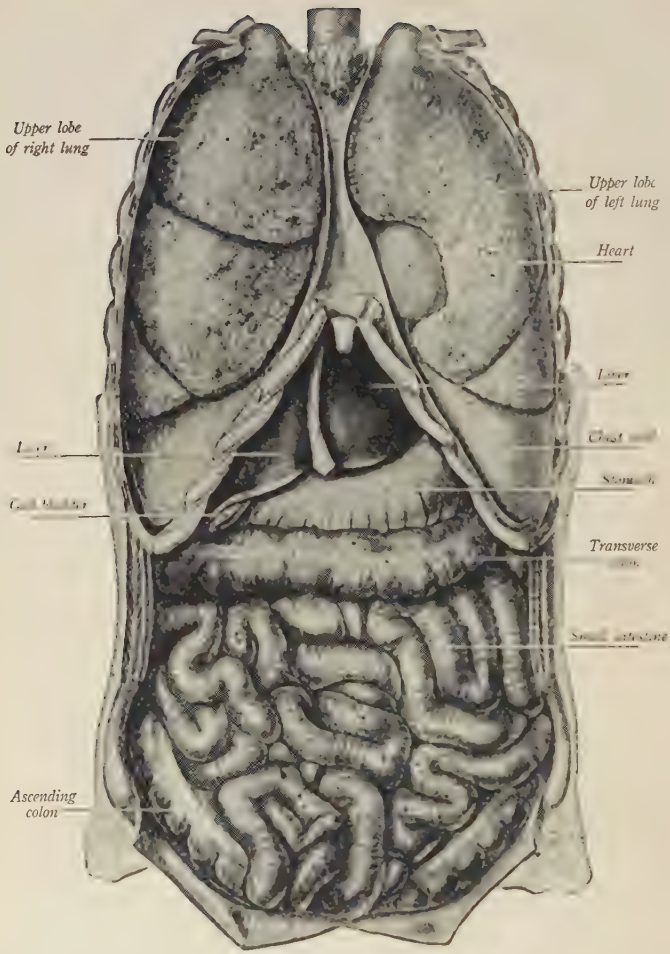


FIG. 3. The thoracic, or pleural, cavity, and the abdominal, or peritoneal, cavity, filled with organs

surfaces of the organs, like the walls of the cavity, are consequently smoothly covered and glide over one another with very little friction. The preservation of these pleural and peritoneal linings in their normal condition is a matter of great importance; when inflamed or otherwise injured their surfaces become roughened, and *adhesions* of connective tissue often develop between them which fasten the organs together or to the walls of the cavity, so that surgical interference is sometimes necessary. Pleurisy is such an inflammation of the pleura, peritonitis of the peritoneum; and both are very serious conditions.

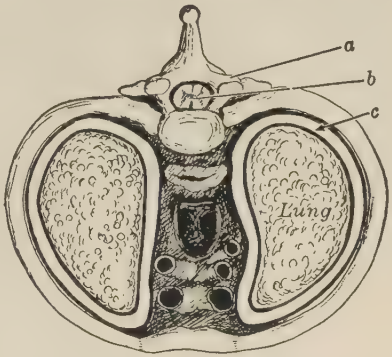


FIG. 4. Cross section of the chest, anterior to the branching of the trachea

a, a vertebra of the spinal column; *b*, spinal cord; *c*, the pleural cavity (which is exaggerated for the sake of clearness, the surface of the lung being actually in contact with the body wall). The esophagus and trachea, together with several large arteries and veins, are shown in the mediastinum, ventral to the vertebra and in the order named

6. Attachment of the organs to the walls of the pleural and peritoneal cavities. The pleural cavity is completely divided by a median partition of connective tissue (the *mediastinum*), within which are found the *trachea*, the *esophagus*, the *great blood vessels*, and — lying within a special cavity of its own — the *heart*. Approximately halfway from the anterior to the posterior border of the mediastinum the trachea divides within that membrane into two tubes, or *bronchi*, which pass through the mediastinum outward, one to the *right lung*, the other to the *left*. The pleural lining of the mediastinum is pushed outward by these tubes and, as they end in the lungs, forms the pleural covering of the

latter (Fig. 6). Consequently the organs of the pleural cavity either lie within the mediastinum (heart, esophagus, trachea, etc.) or else are covered by extensions of the mediastinal pleura (bronchi and lungs).

The abdominal cavity is not similarly separated into right and left halves; but a membrane, the *mesentery*, passes

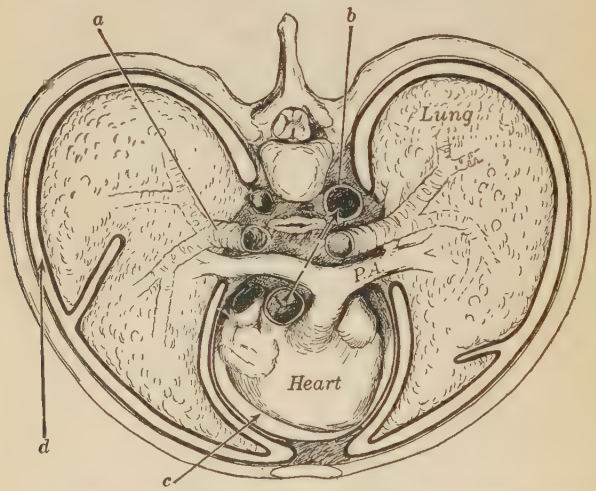


FIG. 5. Cross section of chest, posterior to branching of trachea

a, bronchus, entering the lung; *b*, the aorta, cut at its origin and again at the descending part of its arch; *c*, the pericardial space; *d*, the pleural cavity; *P.A.*, the pulmonary artery

ventrally from the dorsal wall to the stomach and intestine, which are slung in it somewhat as a man lies in a hammock. The line of attachment of this mesentery to the small intestine is much longer than that of its attachment to the body wall; hence it has the general shape of a ruffle, or flounce — an arrangement which permits the suspension of the very long intestine (20 to 25 ft.) from the comparatively short median dorsal body wall (see Fig. 7). The great arteries and veins lie in the mesentery near the dorsal body wall,

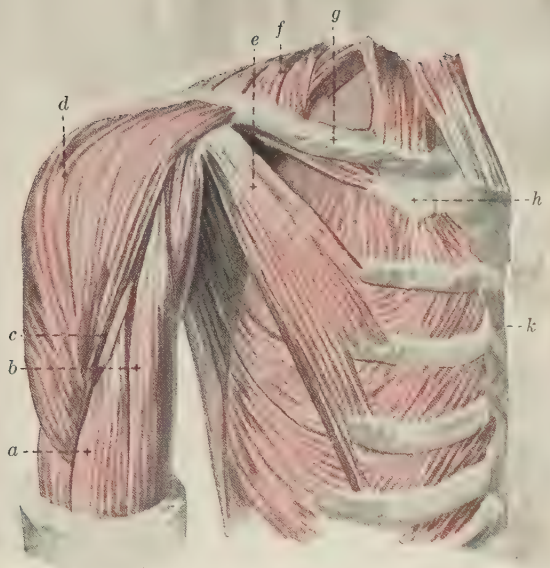


PLATE A. Second layer of muscles of the breast, exposed by dissecting away the pectoralis major. After Spalteholz

a, *b*, the two "heads" of the biceps; *c*, cut end of the pectoralis major; *d*, deltoid; *e*, pectoralis minor; *f*, trapezius; *g*, clavicle; *h*, first rib; *k*, sternum. Note the direct attachment of the intercostal muscles to the ribs (p. 13)

PLATE B. A portion of the small intestine. After Spalteholz

Showing its attachment to the flouncelike mesentery, and the course of its arteries (red) and veins (blue) in the mesentery (pp. 16 ff.)

and branches are distributed from them to the intestine within this expanding membrane (see plate facing page 17).

The kidneys do not lie movably suspended in the abdominal cavity, as do the intestines, but are large organs, one on each side, situated near the spinal column and dorsal to the abdominal cavity, from which they are separated by the peritoneum. Arteries and veins are supplied to them from the large median artery and the median vein already referred to (*aorta* and *vena cava*, Figs. 8 and 17), and these renal arteries and veins are likewise outside the abdominal cavity.

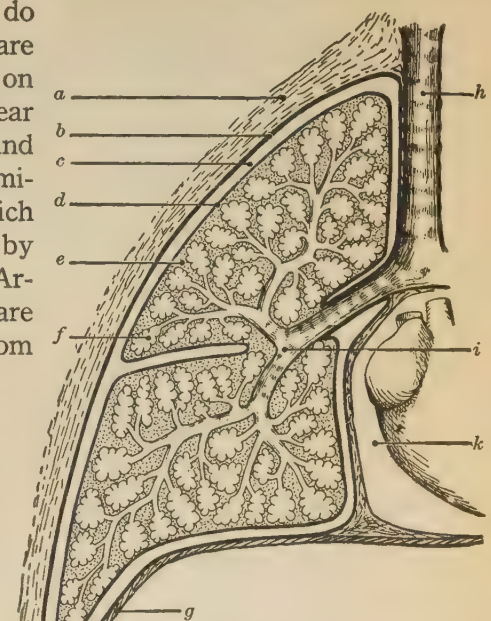


FIG. 6. Diagrammatic vertical right-to-left section of the right thorax

a, muscles and ribs forming the body wall; *b*, pleura, lining the same; *c*, the pleural space or cavity; *d*, the pleural covering of the lung; *e*, connective tissue of the lung; *f*, alveoli of the lung; *g*, diaphragm; *h*, trachea; *i*, right bronchus, branching; *k*, the pericardial space, in which lies the heart. Note the division of the lung into two lobes

The relation of the other organs to the peritoneum is more complicated, notably in the case of the liver; but in all cases the organs are inclosed, or wrapped, either in a fold of the peritoneum, as is the kidney, or in a fold of the mesentery, as is the intestine; and their blood and nerve supplies run to them in similar folds.

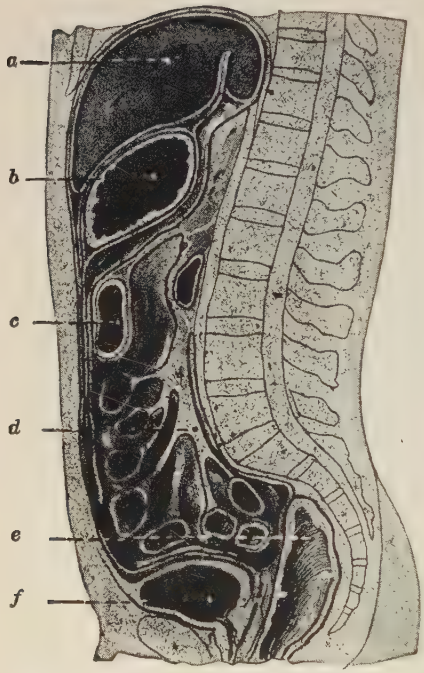


FIG. 7. Median dorsoventral section of the trunk in the abdominal region, showing the suspension of the stomach and intestine by the mesentery. After Spalteholz

a, liver; *b*, stomach; *c*, transverse colon; *d*, mesentery; *e*, rectum; *f*, urinary bladder

7. The axial skeleton. The bones and cartilages of which the skeleton is composed may be classified into an *axial skeleton* (of the head, neck, and trunk) and an *appendicular skeleton* (of the arms and legs). The axial skeleton comprises (1) the backbone, or vertebral column, (2) the ribs and breastbone, and (3) the skull (Fig. 15).

8. The backbone, or vertebral (spinal) column. This is composed of separate irregular ring-like bones, or *vertebræ*, placed one above another and bound together by bands of strong connective tissue known as ligaments. The thick-walled tube thus formed contains and protects that part of the nervous system called the *spinal cord*. It is customary to divide the vertebral column into the following regions:

Cervical: 7 vertebræ of the neck.
Thoracic: 12 vertebræ of the chest, to which ribs are attached.
Lumbar: 5 vertebræ of the "small of the back."
Sacral: 5 vertebræ (fused together) to which the large hip bones are attached.
Coccygeal: 4 or 5 very small, simple vertebræ (constituting the skeleton of a rudimentary tail and corresponding to the tail of lower animals).

When one looks at the spinal column from behind, the vertebræ are seen to be placed one upon another, but *all in the median dorsoventral plane of the body* (see Fig. 7). Seen from the side, however, several curves come into view, as shown in Fig. 12. On the ventral side, in the cervical and upper thoracic region, the curvature is slightly convex; in the thoracic region it is quite concave; in the lumbar region slightly convex; and finally in the sacral region quite concave again. It may well be asked how these separate vertebræ, piled, as it were, one above another, maintain their proper relative positions. This is partly due to the shape of the individual vertebræ, partly to the ligaments (p. 12) which pass from one vertebra to another and limit the movements of each, and partly to the action of muscles which are placed upon opposite sides of the vertebræ and by their *antagonistic* action hold them in place. The action of muscles and ligaments upon the bones may be illustrated by two blocks of wood held together by two rubber bands (*m*, *m'*, Fig. 13) slightly stretched; so long as each pair of opposite bands pulls with the same force, the blocks are kept in what we may call their resting position. Here the rubber bands represent two of the antagonistic muscles, which, by maintaining a steady and equal pull on the opposite sides of the vertebræ, keep them

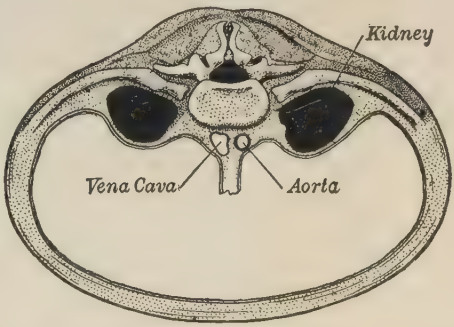


FIG. 8. Diagrammatic cross section of the abdominal cavity

Showing the relation of the kidneys and great blood vessels to the peritoneum. The intestine has been removed, the cut border of the mesentery being shown

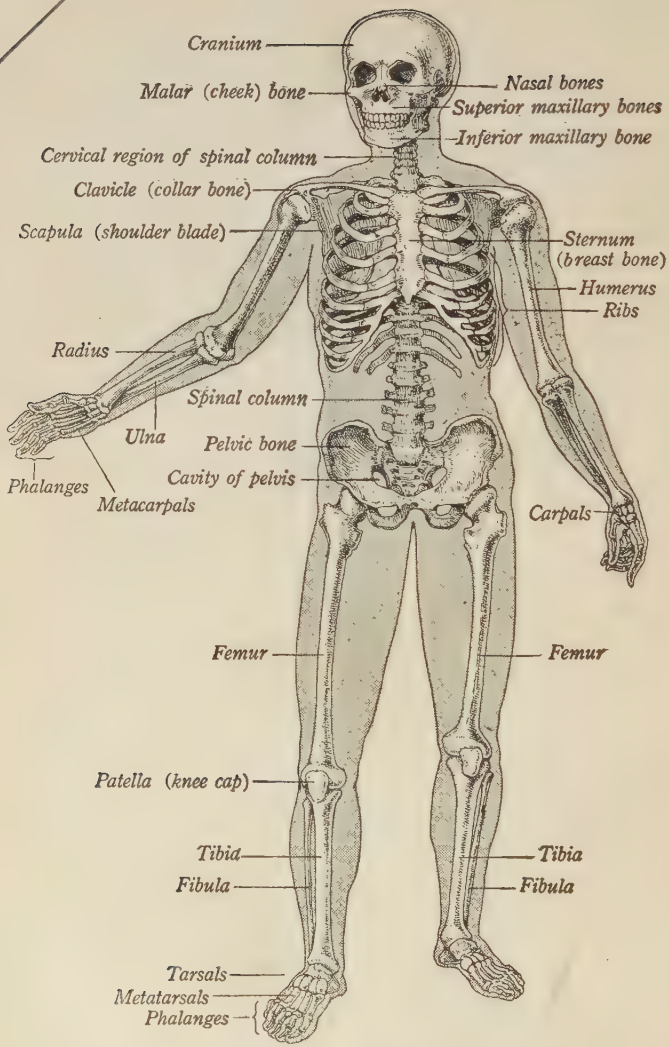


FIG. 9. The skeleton entire

in place. Should one pull harder than its antagonist, as when a muscle contracts (see Chapter IV), the antagonist will be stretched and the bones become inclined toward one another, as shown in the right-hand portion of Fig. 13.

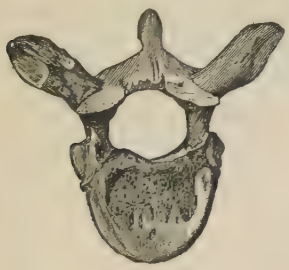


FIG. 10. Sixth thoracic vertebra
Seen from above

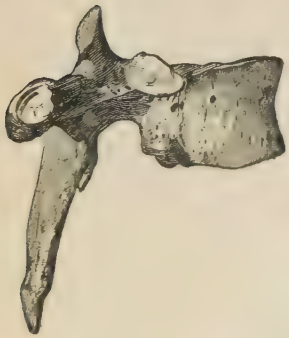


FIG. 11. Sixth thoracic vertebra
Seen from the side

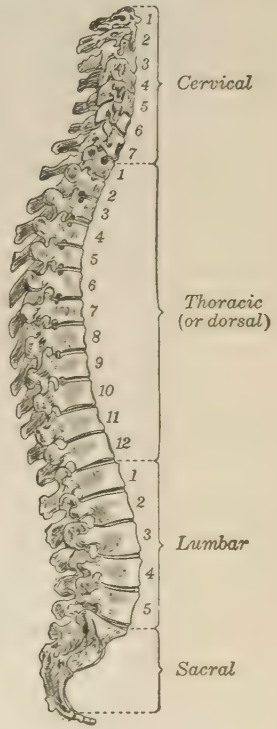


FIG. 12. The vertebral column
Seen from the side

This principle of muscular antagonism is quite general in the maintenance of the proper relative positions of bones in the body. Almost every joint is the theater of such plays of antagonistic muscles, which serve the double function of

keeping the bones in proper position with regard to one another and of producing movement at the joint, the amount of this movement being limited by the slack but inextensible connective-tissue ligaments which bind the bones together. In Fig. 13 both the shortening of the muscle and the slackness of the ligaments are purposely exaggerated, in order to represent more clearly the functions of these tissues. Ligaments may also guide the movement of bones by preventing motion in one direction or another.

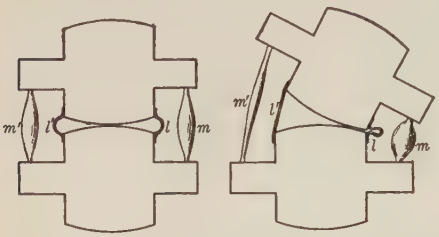


FIG. 13. Model showing the action of muscles on two vertebræ, and of the ligaments (*l*, *l'*) in limiting the amount of movement

The contraction of the muscle *m* stretches its antagonist *m'*. The amount of movement is greatly exaggerated

9. The ribs. Each rib consists of a *bony* and a *cartilaginous* portion. The former articulates (that is, forms a joint with) the vertebral column, while the latter continues this bony portion to the ventral median *breastbone*, to which it is directly joined. The ribs form the framework for the thorax and are of importance in respiration. They may be lifted or lowered by muscles which connect them with the vertebral column and other parts of the skeleton (see Fig. 14).

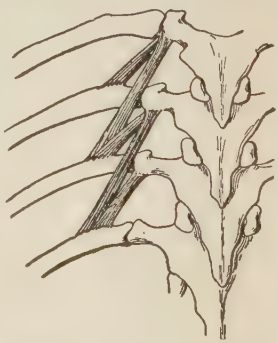


FIG. 14. Dorsal view of vertebræ and ribs

Showing some of the muscles which lift the ribs

10. The skeleton and the central nervous system. The skull consists of the bones of the *face* and those of the *cranium*, the latter holding the brain. It is supported on the

spinal, or vertebral, column, whose ringlike vertebræ inclose a bony canal continuous with the cranial cavity. This is known as the *spinal*, or *vertebral, canal*, in which lies the *spinal cord*[1] — the continuation of the central nervous system posterior to the brain.

Nerves, which pass through small openings in the cranium and between the vertebræ, leave the brain and cord and end in the muscles, skin, glands, and other organs of the body (see Chapter VII).

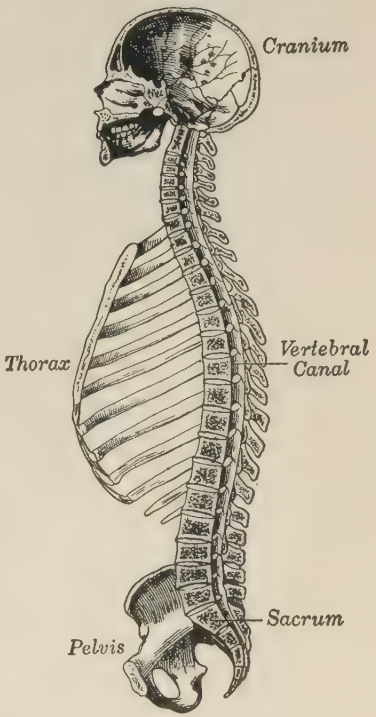


FIG. 15. Median dorsoventral section of the skeleton

11. The appendicular skeleton. The bones of the arm, leg, hand, and foot may readily be felt and it will be very helpful to examine them while studying the tables given on the next page. We may at this point, however, call attention to the similarity in the number and form of the bones of the arms and legs, a similarity which is not only helpful in mastering their names and arrangement but is also suggestive of the similarity of function in quadrupeds, both pairs of limbs in these animals being organs of locomotion.

[1] The terms "spinal cord," "spinal column," and "spinal canal" are sometimes confused by beginners. The spinal column is the entire bony framework formed by the vertebræ — the whole backbone; it surrounds the spinal canal, which, in turn, contains that part of the nervous system known as the spinal cord.

ARM

Humerus, single long bone of the upper arm.
Radius and *ulna*, two nearly parallel bones of the forearm.
Eight small irregular bones of the wrist.
Five parallel bones of the palm.
Bones of fingers { Thumb, two bones. / Other fingers, three bones.

LEG

Femur, single long bone of the thigh.
Tibia and *fibula*, two nearly parallel bones of the lower leg.
Seven small irregular bones of the ankle and heel.
Five parallel bones of the instep.
Bones of toes { Great toe, two bones. / Other toes, three bones.

The legs are attached to the vertebral column by the large *hip bones*, which articulate directly and immovably with the *sacrum*[1]; but the *humerus*, or bone of the upper arm, articulates on each side with one of a pair of bones which form the *shoulder girdle*, or skeleton of the shoulder region; this pair consists of the *collar bone* (*clavicle*) ventrally and the *shoulder blade* (*scapula*) dorsally. The clavicle articulates with the head of the breastbone; otherwise the shoulder girdle, with the arm attached to it, is connected with the axial skeleton by muscles only. A wide range of movement is thus secured at the shoulder joint.

12. Organs of digestion. The digestive system consists essentially of a long tube, the *alimentary canal*, passing through the body.[2] Into this tube, at various points, ducts from a number of glands pour *digestive juices*. The alimentary canal begins with the *mouth cavity* and its familiar organs, the *teeth*, the *tongue*, etc.; this cavity opens posteriorly into that of the *pharynx*, into which also opens the *nasal cavity*, separated from the mouth only by the *palate* (see Fig. 16).

[1] The sacrum and the two hip bones together form the *pelvis*.
[2] See Figs. 3 and 7 for the general arrangement of the organs of digestion.

On the ventral side of the pharynx, just beyond the root of the tongue, is the slitlike opening of the windpipe (see section 13); posteriorly the pharynx is continued in the long gullet, or *esophagus*, a tube which passes downward through the neck and thorax (within the mediastinum) to join the stomach, which it enters immediately after passing through the diaphragm.

The *stomach* is a large pouch with contractile walls permitting adaptation of its size to the bulk of food it may contain. Its situation is shown in Fig. 7, which also shows how it opens on the right side of the body into the very long, coiled *small intestine*. The coils of this part of the tube may be followed for from twenty to twenty-four feet, to the large intestine, into one side of which it opens. The *large intestine*, or *colon*, consists of three portions; the first *ascending* on the right side to the general level of the stomach, the second passing *transversely* at this level from right to left, and the third *descending* on the left side to the *rectum*, the posterior terminal portion of the digestive tube.

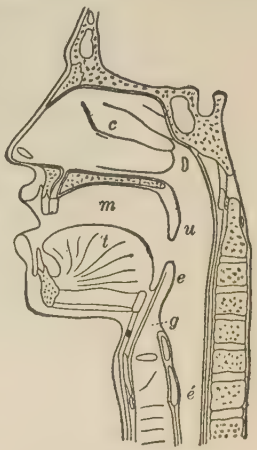


FIG. 16. Diagrammatic median dorsoventral section of the nasal and throat passages

c, nasal cavities; *m*, mouth cavity; *t*, tongue; *e*, epiglottis; *g*, glottis, or opening from the pharynx into the trachea; *u*, the end of the soft palate; *é*, esophagus

Numerous glands pour secretions through ducts into the digestive tube, the more important, with their places of discharge, being the following: salivary glands (see Chapter III) — mouth; liver — beginning of small intestine; pancreas — beginning of small intestine (see Fig. 56). Smaller glands empty into the stomach and intestines at numerous places. These glands supply substances necessary in the digestion of food materials.

13. The organs of respiration. The organs of respiration consist of the right and left *lungs* (see Fig. 5), from each of which a single *bronchus* (pl., *bronchi*) leads to the *trachea* (or *windpipe*). The walls of the trachea and bronchi are kept from collapsing by successive rings of cartilage. Anteriorly the trachea opens into the pharynx through the *larynx*, or *voice box*, the cartilages of which may be felt in the throat at the root of the tongue. The familiar hoarseness which accompanies inflammatory roughening of the lining of the larynx shows how important is this organ in the production of the voice. The respiratory and digestive paths cross in the pharynx, the former reaching the exterior through the nose, the latter through the mouth.

14. The organs of circulation. The position of the heart and the great blood vessels in the thorax has been described on page 15. The heart is essentially a large mass of muscle containing a cavity which is divided into right and left halves, wholly separate from each other. The cavity on each side is divided into that of the large *ventricle*, with very thick walls, and that of the much smaller *auricle*. The heart is thus composed of right and left auricles and right and left ventricles. Valves are so placed in the heart as to allow blood to flow in one direction only (see Fig. 71).

The *arteries* are tubes which carry the blood to the tissues, and from each side of the heart a single artery takes its origin — the *pulmonary artery* from the *right* ventricle, and the *aorta* from the *left* ventricle. The pulmonary artery supplies the lungs with blood, while all other organs are supplied by the aorta.

The *veins* are tubes which conduct the blood from the various organs to the heart. Beginning in the tissues as microscopic tubes, they unite to form larger and larger tubes as they approach the heart; those visible through the skin of the hand may be regarded as of medium size; as the

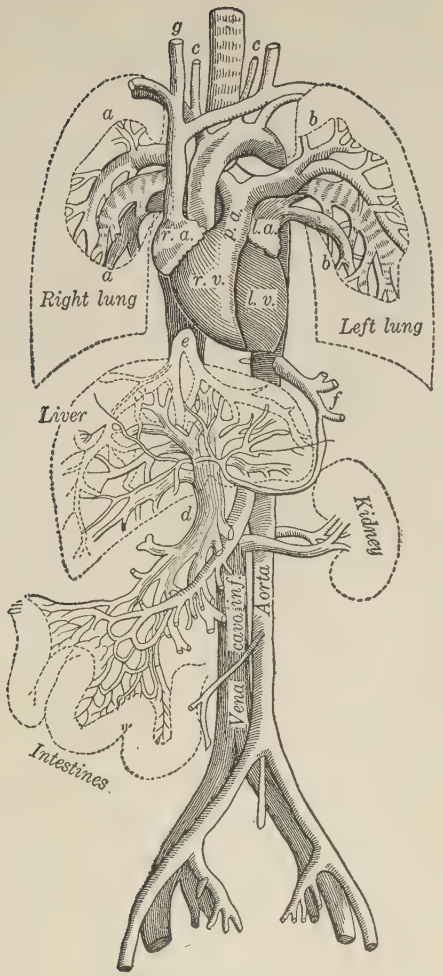


FIG. 17. Diagram of the circulation of blood

r.a., right auricle; *l.a.*, left auricle; *r.v.*, right ventricle; *l.v.*, left ventricle; *p.a.*, pulmonary artery; *a*, pulmonary artery and vein of right lung; *b*, pulmonary artery and vein of left lung; *c*, carotid artery to head, showing branch of left subclavian artery; *d*, portal vein; *e*, hepatic vein; *f*, hepatic artery; *g*, jugular vein, bringing blood from head and neck

union goes on, the size of the vessels increases until, finally, at the heart there are only two *great veins* on the right side (*superior vena cava* and *inferior vena cava*) and four on the left (*pulmonary veins*). The *venæ cavæ* bring blood back from those portions of the body which are supplied by the aorta, that is to say, from all parts of the body except the lungs; the pulmonary veins bring blood back only from the lungs, that is to say, from the organs supplied by the pulmonary arteries. The venæ cavæ empty into the right auricle, the pulmonary veins into the left auricle. The general arrangement of heart, arteries, and veins is shown in Fig. 17; and the illustrations in Chapter IX (especially Figs. 74 and 75) should also be consulted.

The blood flows in the following circuit:

Pulmonary circulation	Right ventricle to pulmonary artery to lungs to pulmonary veins to
Systemic circulation	left auricle to left ventricle to aorta and its branches to all organs of the body (except the lungs) to veins which unite to form the venæ cavæ to right auricle to right ventricle

Thus the blood which leaves the left ventricle flows to the different organs of the body (except the lungs) and returns by way of the veins to the right side of the heart; thence it passes through the lungs and again to the left auricle and ventricle, thus completing the "circulation." The term "circulation," strictly speaking, is applied to the entire circuit which the blood must traverse before it returns again to the point from which it started; it is often convenient, however, to use it to denote the course from the right ventricle to the left auricle, or from the left ventricle

to the right auricle; in this case we speak of the former as the *pulmonary* and of the latter as the *systemic*, or *aortic*, circulation. In this sense there may be said to be a "double" circulation.

The veins have thinner walls than the corresponding arteries, and those of the systemic circulation contain purplish or even bluish blood, while the arteries of the same circulation contain bright-scarlet blood. The bright color of the arterial blood is due to the fact that it contains more oxygen. The change from purple to scarlet occurs in the lungs, and the reverse change in the organs supplied by branches of the aorta. Consequently the blood of the pulmonary arteries is blue, or venous, in color and that of the pulmonary veins is scarlet, or arterial. Fig. 17 should be consulted.

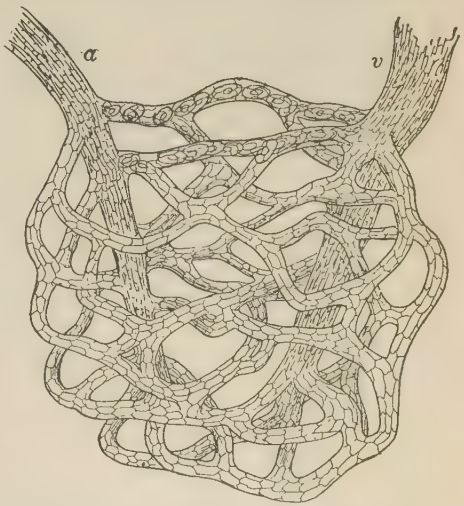


FIG. 18. A network of capillaries, with the artery *a* and vein *v* (highly magnified)

15. The course and branches of the pulmonary artery and vein. Soon after leaving the right ventricle the pulmonary artery divides into two branches, one going to each lung. Each of these further divides as it plunges into the substance of the lung alongside the bronchus. The course of the four pulmonary veins may be similarly traced into the lungs, from which they bring the blood back to the heart (Fig. 17).

16. The course and branches of the aorta. The aorta passes anteriorly from the left ventricle, but very soon arches dorsally and posteriorly, forming the *arch of the aorta* (Fig. 17); the general course of the artery can be best understood from the figures or from actual dissection. The arch of the aorta is continued in the large *dorsal aorta*, which passes posteriorly on the left side of the mediastinum near the spine, through the diaphragm, to the lower portion of the abdominal cavity, where it divides into two large arteries which supply blood to the hips and legs. From the arch of the aorta three large arteries pass to the head, neck, shoulders, and arms; from the thoracic dorsal aorta arise a number of small arteries which supply the muscles and other organs of the thoracic wall; immediately after passing through the diaphragm two large branches go to the stomach, spleen, liver, pancreas, and a large part of the small intestine; posterior to these the *renal arteries* pass right and left to the kidneys, and still further down a large artery supplies the lower small intestine and the large intestine. The supply to the legs has already been mentioned. Other small arteries arise from the

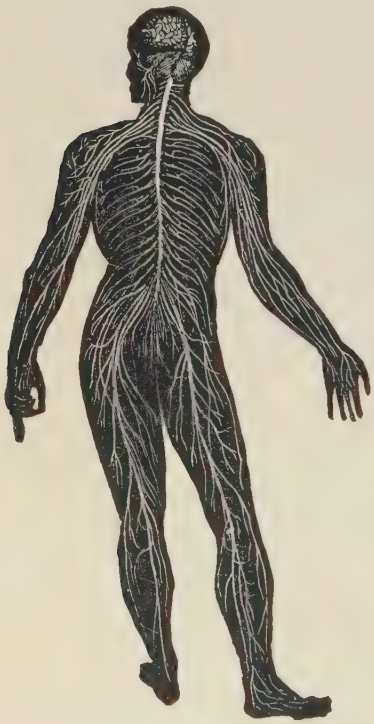


FIG. 19. The general arrangement of the nervous system (dorsal view)

abdominal aorta and are distributed to the muscles and skin of the back. The arteries and veins of the stomach and intestine lie in the mesentery (see plate facing page 17) and their course may be readily traced in a dissection.

17. The course and branches of the venæ cavæ. The blood which has thus been distributed from the aorta returns to the opposite side of the heart through the veins which ultimately form the two venæ cavæ. In general, it may be stated that the veins of those organs which are anterior to the diaphragm form the superior vena cava, while those posterior to the diaphragm form the inferior vena cava. The larger veins usually run near and approximately parallel to the larger arteries. This is the case with those from the arms and legs, the kidneys, and the muscles of the trunk. One notable and very important exception, however, is found in the venous supply of the stomach, spleen, and intestines, the veins of which unite to form a single large vein (*portal vein*) which passes to the liver and breaks up into smaller vessels; the blood which has thus passed through the liver, where important changes were effected, is finally collected in the *hepatic vein* and poured by this into the inferior vena cava just before the latter passes through the diaphragm on its way to the right ventricle (Fig. 17; see also Fig. 74).

FIG. 20. Nerve trunks of the right arm

18. The capillaries. The blood which enters an organ through the arteries passes to its veins through a system of microscopic tubes (Fig. 18), the capillaries (Latin *capilla*, "a hair"); these may be readily seen under the microscope in the web of a frog's foot. From the foregoing description of the course of the circulation it will be observed that generally the blood must pass through one set of capillaries in going from the aorta to the venæ cavæ or from the pulmonary artery to the pulmonary vein; but the blood which flows through the capillaries of most of the abdominal organs (stomach, intestines, spleen) must pass also through a second set of capillaries, namely, those of the liver, before it can return to the heart.

19. Organs of the nervous system. The skull and the spinal column (p. 23) are chiefly occupied by the *brain* and the *spinal cord*, respectively, and from each of these principal organs of the nervous system branches consisting of cords of nervous substance, the *nerves*, pass out through small holes in the skull or spinal column and are distributed to all the other organs, where they terminate in peculiar structures called *end organs*. The optic nerve, for example, ends in the retina, the auditory nerve in the inner ear, and motor nerves in muscles — the nerve endings in these different organs differing materially in structure and arrangement.

Fig. 19 gives some idea of the general arrangement of the nervous system. The nerves to the shoulder, arm, and hand will be seen to arise from the cervical region of the spinal cord; those for the trunk, from the dorsal and lumbar regions; those for the legs, from the sacral region. The head and face receive nerves from the posterior portions of the brain. The dissection of the arm in Fig. 20 shows more accurately the main nerve trunks to that region. Further information with regard to the structure of the nervous system will be given in Chapters VII, XIV, and XV.

CHAPTER III

THE FINER STRUCTURE OF TWO TYPICAL ORGANS, GLANDS AND MUSCLES. THE CONNECTIVE TISSUES. THE LYMPHATIC SYSTEM

In the previous chapter we have examined the general construction of the human machine as regards its more conspicuous parts or organs, and especially their location, — whether internal or external, dorsal or ventral, anterior or posterior, on the right or on the left, — their relations to certain important cavities, and their combination to constitute the mechanism which we call the human body. We must now push our examination further and investigate the finer structure of some of the more important parts of the machine. For this purpose we may select two typical organs, a gland and a muscle, the one unfamiliar, by name at least, to most people, the other well known in the form of steaks, chops, roast beef, and other meats.

1. What is a gland? A gland is a mass of tissue, generally softer than muscle and of no special size or shape, though often rounded or egg-shaped. The gland most easily seen is the milk gland, or udder, of the cow. This is a large mass of soft tissues devoted to manufacturing or *secreting* milk. In general, glands are manufacturing organs for the preparation of saliva, gastric juice, bile, tears, sweat, or other secretions. Some have tubes, or *ducts*, through which their secretions are carried away; others have no such outlets and hence are known as *ductless* glands. Glands vary in size from some which are microscopic to the huge liver, which is the largest single organ in the human body (see

Fig. 3). The *pancreas*, or "sweetbread," of the calf is an excellent gland for the beginner to dissect or study.

2. A typical gland. If we have before us the whole or a part of any typical gland, we find that we are dealing with a comparatively soft and sometimes even pulpy mass held together by a loose mesh or network of harder, tougher, and more or less fibrous materials. A pancreas or a liver, if entire, shows conspicuous *lobes*, and in the pancreas these lobes are plainly subdivided into smaller lobes, or *lobules*. In favorable specimens tubes may be seen connected with the gland; some of these are blood vessels supplying blood to the gland, and one of them is a duct draining away from it the liquid which the gland has manufactured or secreted. After such a preliminary examination of some edible gland, preferably the pancreas, we may pass on to consider in greater detail one of our own *salivary* glands, of which we have three pairs, namely, the *parotid*, the *sublingual*, and the *submaxillary* glands.

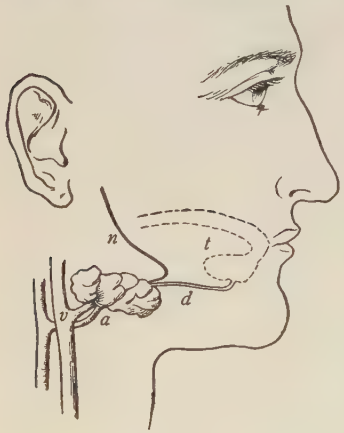


FIG. 21. Diagram of submaxillary gland

d, its duct; *n*, its nerve; *a*, its artery; *v*, its vein; *t*, tongue

3. The structure of the submaxillary gland. The two submaxillary glands lie, one on each side of the face, embedded in the tissues between the lower jaw and the upper portion of the neck. From each gland a duct passes forward in the tissues forming the floor of the mouth, into which it opens by one of the small eminences, or *papillæ*, under the tongue. Through this duct the gland pours into the mouth its secretion, *saliva*.

If the gland were to be cut in two in any direction with a sharp knife, we should see at once that it is composed of separate parts, or *lobes*, and that these lobes are still further divided into smaller portions, or *lobules*. The lobules and lobes are bound together with a rather loose connective tissue which is continuous with a somewhat denser layer surrounding the gland and forming its *capsule*; the connective tissue between the lobes forms the *primary septa* (sing., *septum*) and that between the lobules the *secondary septa*. The relation of these structures is shown in Fig. 22. With the aid of the microscope we find that each lobule is still further divided by connective tissue into flask-shaped structures, or *alveoli* (sing., *alveolus*); in these the secretion, saliva, is manufactured and from them it is discharged into the duct of which the alveoli are the blind ends (Fig. 23).

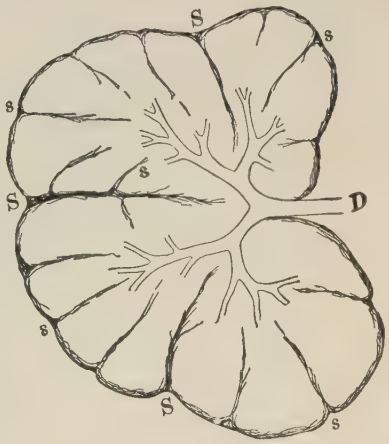


FIG. 22. Diagram of a cross section of a gland

Showing its division by primary septa (*S*) into lobes and by secondary septa (*s*) into lobules; also the origin of the larger branches of the duct (*D*) in the lobes and lobules. The beginnings of the duct are shown in Figs. 25 and 26

The whole gland may be compared to a large bunch of grapes; the main tubular duct of the gland branches (in the septa of connective tissue) very much as the stem of the bunch of grapes branches; and just as the branches and subbranches of the stem lead, when followed up, to the grapes themselves, so the branches of the duct lead to the alveoli of the gland. If now we pack the bunch of grapes in a small basket of straw, as Malaga grapes are packed,

so that the straw fills loosely the spaces between the individual grapes and the branches of the stem, we shall have something with which to compare the arrangement of the connective tissue in relation to the rest of the gland — the straw standing for the connective tissue in which the ducts and alveoli are embedded, and the basket for the capsule.

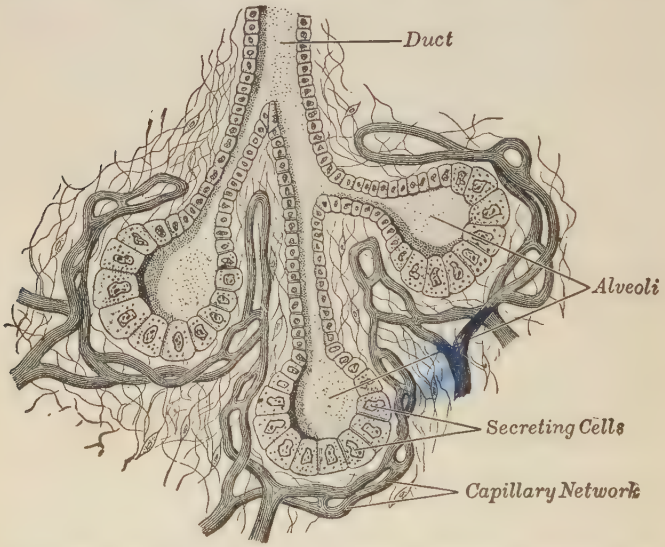


FIG. 23. The origin of the duct of a gland in alveoli, together with the connective tissue and blood vessels

4. Minute structure of ducts and alveoli. The ducts and alveoli are not thin-walled structures like metal tubes and flasks. Each is lined with one or more layers of cells, which in the former are somewhat flat and in the latter thick and closely set (Fig. 24). The definition and essential structure of a cell was given in Chapter II, where it was pointed out that all organs are composed of cells and that all cells consist of two essential parts — nucleus and cytoplasm.

The glands, muscles, and all other organs consist of cells,

just as all the branches of the military service — the infantry, the cavalry, the artillery, the engineers, and so forth — consist of men. The cell is the anatomical unit of these organs, as the soldier is the unit of the army; in both cases the anatomical units, differing in equipment and training, perform different kinds of work, yet have the same essential

FIG. 24. Section of a portion of a salivary gland (magnified 500 diameters). After Kœlliker

The duct *d* divides into the two branches *d'* and *d''*, one of which ends in the alveoli, *a*, *a*. Neighboring alveoli, *a'*, *a'*, whose ducts are not in the plane of the section, are also shown. In some cells this section does not include the nucleus, which would be in the preceding or the succeeding section

structure; and the cells are combined into brigades, divisions, or corps, as tissues and organs; they make of the body an army organized to fight its way through the vicissitudes and against the obstacles of life.

5. The structure of the biceps muscle. The biceps muscle is familiar as the mass of flesh lying on the front of the upper arm and bulging somewhat when the arm is bent at the elbow, especially when one "feels his muscle" or when a weight is being lifted by the hand. Fig. 25 shows this muscle with the bones to which it is attached. It consists of two

portions: a central, thick, red part, known as the *belly*, soft when the muscle is at rest, hard when it is contracted; and cordlike strings, or *tendons*, two at the upper end and one at the lower, by means of which the muscle is attached to two bones of the shoulder girdle and to one of the forearm. When the belly of the muscle shortens, the points *a* and *b* are brought closer together and the arm is bent, or flexed, at the elbow. This drawing together, or *contraction*, is the special work, or *function*, of muscles in general.

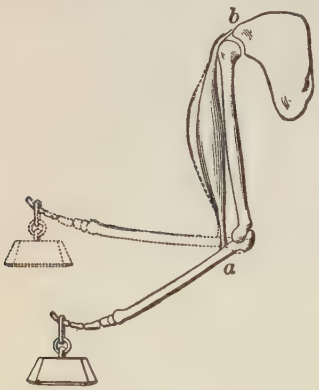


FIG. 25. The biceps muscle of the arm

The resting condition is shown by the solid lines, the contracting condition by the dotted lines

Everyone has seen the cross section of a muscle in a raw beefsteak. This shows that the muscle as a whole is surrounded by a sheath of connective tissue which contains more or less fat; *septa* pass inwards, dividing the muscle into lesser red masses known as *fasciculi*, or bundles, and these are further subdivided into secondary fasciculi by secondary septa, very much as the gland is subdivided into lobules.

A longitudinal section shows that the fasciculi run from tendon to tendon, and microscopic examination proves that the general connective tissues of the belly of the muscle are continuous with that of the tendon. The tendon itself is a peculiarly strong and inextensible variety of connective tissue consisting chiefly of parallel fibers which are specially fitted to transmit to the bone the pull of the belly of the muscle.

6. The muscle fibers. Examination of the structure of one of the finer fasciculi in the belly of the muscle shows that it is composed of threads, or fibers, which at first sight differ

greatly from the secreting cells of the gland. These are the *muscle fibers*. They are 1 to 1½ inches in length and from $\frac{1}{2500}$ to $\frac{1}{250}$ of an inch in thickness, thus being from 250 to 2500 times as long as wide, and comparable in shape to a long leather shoestring rather than to a sausage. Each fasciculus contains hundreds or even thousands of fibers. The fibers always run lengthwise of the fasciculus, but, as a usual thing, do not extend its entire length, as obviously follows from the fact that a single fasciculus of the biceps is several inches in length. The fibers are inclosed in a very thin transparent membrane, the *sarcolemma*, and are bound into bundles (or fasciculi) by the same fine connective tissues seen between the alveoli of a gland.

FIG. 26. Tendon (highly magnified)
Showing the fiber bundles separated

FIG. 27. One end of a muscle fiber
Showing the attachment of the tendon fibers to the sarcolemma

To the end of the sarcolemma are attached fine fibers of connective tissue which pass into the tendon (Fig. 27). Indeed, the fibers of the tendon are the collected fibers from the sarcolemmas of all the muscle fibers. For this reason the part of the muscle near the tendon is tough meat, while that in the belly of the muscle is tender, owing to the smaller number of connective-tissue fibers.

7. The muscle fiber a cell. The muscle fiber at first sight does not seem like the typical cell already described, with nucleus and cytoplasm; for when examined in the fresh condition the only obvious points of structure seen in it are striking *cross striations* consisting of alternate dark and light bands. It has been shown, however, by ingenious and careful study that the cross striations

are optical appearances produced by the peculiar shape of extremely minute longitudinal rods in the cytoplasm of the muscle fiber and that, immediately under the sarcolemma, there are numerous characteristic nuclei which are easily brought into view by suitable treatment. Briefly, then, the muscle fiber is *a cell with many nuclei*, in whose cytoplasm are found peculiar structures, the *myofibrils*; upon superficial examination these myofibrils not only obscure the nuclei but give to the whole fiber the appearance of cross striation.

FIG. 28. Part of a muscle fiber

Specially prepared to bring out the numerous nuclei

8. How far is the structure of glands and muscles typical of all organs? Both the gland and the muscle are thus composed of *cells*. Although differing considerably in the two organs, these cells possess certain general and fundamental features in common, for each one contains a nucleus (or nuclei) and surrounding cytoplasm. Is the same thing true of all other organs? The muscle and the gland are examples of organs which do active work, but some other organs perform purely passive functions. Such are the bones, which do no work themselves, but upon which the work of mechanical motion is done by the muscles; the tendons, which transmit the pull of muscles; the ligaments, which limit and sometimes guide the motion of bones; and the connective tissues, which bind together other parts of the body. None of these is a working organ in the sense that a muscle or a gland is a working organ, and we are not surprised to find that their structure departs from that of the muscle and gland in that, while nucleated cells are present in all of them, *the great mass of the organ is*

composed of lifeless matter between the cells. In a tendon this consists of very strong parallel fibers (Fig. 26); a ligament shows much the same structure; a bone consists chiefly of lifeless material containing large amounts of mineral matter, with cells lying here and there in spaces which communicate with one another by means of minute channels. The connective tissues, like that which binds the skin to the underlying muscles or that which forms the sheath and septa of glands and muscles, consist essentially of lifeless fibers running in all directions and thus ready to limit the extent of any pull tending to separate unduly the adjacent organs. To organs and tissues of this kind we may give the name of *supporting organs and tissues*, and they form almost the sole exception to the general rule that the essential part of a tissue consists of its cells. The latter statement is true of all active organs, such as the glands and muscles. In the case of the supporting tissues the cells which they contain are the fundamental units of the organ, since they make the intercellular lifeless substance; but the part which the organ plays in the work of the body as a whole is performed by the lifeless substance (connective tissue and bone) which the cells have manufactured and keep in repair.

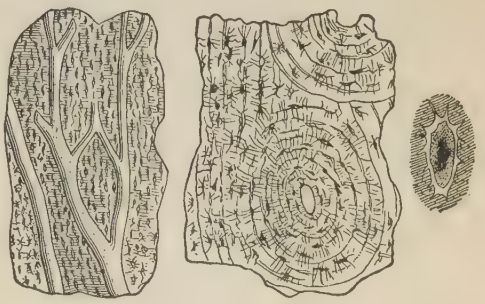


FIG. 29. *A*, longitudinal section, and *B*, transverse section, of bone

Showing the branching and communicating canals — in which are blood vessels and nerves — surrounded by the lifeless bone substance. In the latter are spaces connected with one another by very minute channels. Each of these spaces contains a living cell, shown in *C*

9. The blood vessels are closed tubes in connective tissue. The arrangement of connective tissues is fundamentally the same in gland and muscle. These tissues serve the obvious purpose of binding the anatomical units into organs, but they also perform other functions equally important.

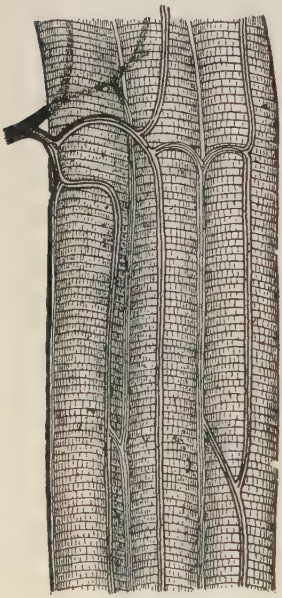


FIG. 30. Three muscle fibers, and an artery breaking up into capillaries between them

We have seen (Chapter II, sect. 18) that each organ receives blood through one or more arteries, and that this blood flows away from the organ through one or more veins. If a colored fluid mass which would afterwards set (for example, a warm solution of gelatin colored with carmine) had been forced into the arteries before we began our examination, we should find that this mass would everywhere be confined in a system of closed tubes which merely lie in the connective tissue. The artery, entering the muscle, branches into smaller and smaller arteries in the general sheath of the organ, or in its septa; from these finer arteries an exceedingly rich network of small thin-walled tubes is given off to the finest connective tissue which surrounds the cells themselves; these tubes are the *capillaries*. They ultimately unite to form the larger veins, which can be traced in the septa to those veins which gross dissection reveals as leaving the organ (see Fig. 30). Through these tubes — arteries, capillaries, and veins — the blood flows; and it is important for us to understand that it is everywhere *confined to them* in its passage through the organs;

nowhere does it come into direct contact with the living cells (save those lining the vessels). Whatever exchange of matter or energy takes place between the blood and the living cells must be through the walls of the blood vessels.[1] These walls are relatively thick in the arteries, usually somewhat thinner in the veins; in the capillaries, however, they are very thin, and it is through these thin capillary walls that all interchanges of matter take place. That the connective tissue surrounding the capillaries bears an important relation to the circulation we shall now see.

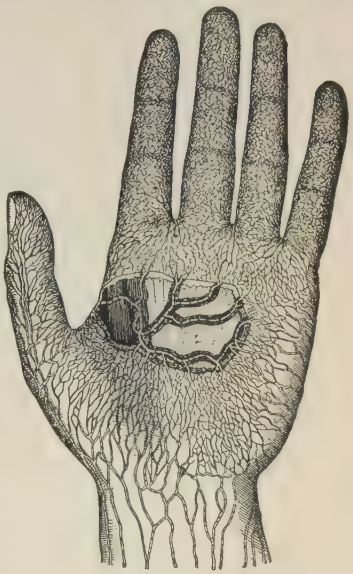


FIG. 31. Lymphatics of the hand, many superficial, and some deeper

10. The lymph spaces of the connective tissue; the lymph. Careful examination shows that the fine connective tissue within which the capillaries are embedded is not a solid or continuous mass, but rather a mass or mesh of extremely fine fibers or bundles of fibers, with here and there connective-tissue cells which keep the fibers in repair. The connective tissue, therefore, is everywhere channeled by irregular spaces running between the fibers and other structures; these spaces communicate freely with each other and contain a colorless liquid known as *lymph*; the spaces of the connective tissue may thus be conveniently described as

[1] The term "blood vessel" is sometimes confusing to the beginner, since it suggests a utensil for holding liquids. In anatomy "vessel" is a name for *tubes, ducts,* or *canals* through which blood or lymph flows.

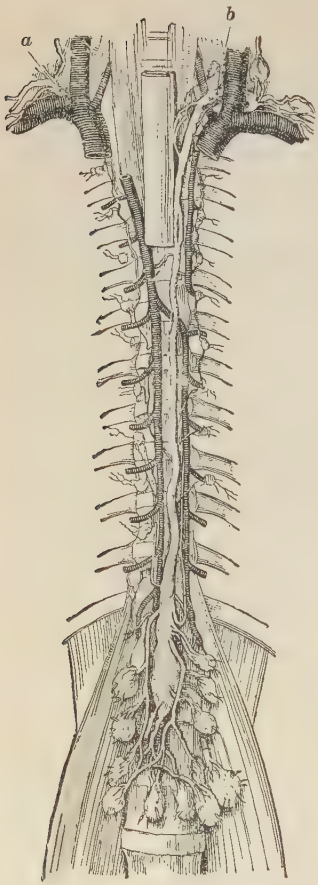


FIG. 32. The two main lymphatic trunks (*a* and *b*), with their openings into the great veins near the heart

The larger of these trunks — that on the left side and known as the *thoracic duct* — returns all the lymph except that from the right side of the head and neck and the right arm and shoulder region

lymph spaces. They serve as communicating channels between the cells and the walls of the capillaries.

11. Origin of the lymph. The lymph which the spaces contain is derived partly from water and soluble food materials which have passed through the capillary walls from the blood and partly from material produced by the neighboring cells (see the next chapter); on the other hand, the cells absorb substances from the lymph which the latter has received from the blood, while the blood, in turn, takes from the lymph various substances discharged from the cells. The lymph thus becomes the means of communication, the middleman, between the living cells of the organs and the nourishing blood, and forms the immediate environment of the cells themselves. In other words, *the cells of muscles, glands, and other organs live in lymph*, just as the human body as a whole lives in air, or a fish in water.

12. The lymphatics. Besides the veins, which convey blood away from an organ, a second system of tubes or vessels passes

out through the capsule. These tubes arise in the lymph spaces of the connective tissue and unite with similar tubes from other regions to form larger and larger trunks, known as *lymphatics*, which ultimately form one or two great trunks and open into the great veins near the heart (see Fig. 32). Through these direct outlets the surplus lymph of the organ

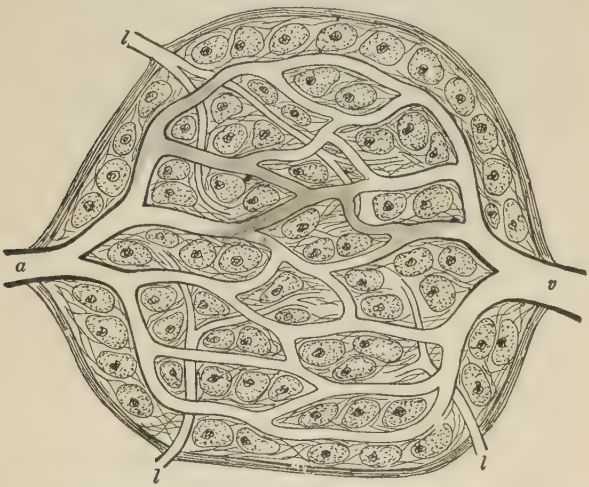


FIG. 33. Diagram of the relation of the cells of an organ to its blood vessels, lymphatics, and connective tissue

a, artery; *v*, vein; *l*, lymphatic

flows in a varying but for the most part continuous stream. This flow of lymph away from an organ is of the very greatest importance in maintaining the normal environment of the cells.

13. Function of the lymph flow from an organ. It is clear from inspection of Fig. 33 that there is a steady flow of liquid from the capillaries, through the lymph spaces of the connective tissue, over the surfaces of the living cells or of any intervening capillaries, to the lymphatics. The cell is

thus bathed not by a stagnant medium but by one which is in gentle movement — one which brings to all parts of its surface the food which it needs and immediately carries away from all parts of its surface to the adjacent capillaries the products of its activity. By providing this outlet from the lymph spaces the lymphatics render possible the movement of lymph within the organ itself, whereby material is readily transferred from the cell to the capillaries and from the capillaries to the cell.

14. Distribution of nerves to muscles and glands. The distribution of nerves resembles that of the arteries, the larger nerve trunks being found in the septa, and their fine ultimate branches being distributed by way of the connective tissue which surrounds the cells, in whose neighborhood or even within whose substance they finally end. As we shall see in subsequent chapters, it is the function of the nerves to arouse the gland cells or muscle fibers or other cells to activity.

15. Summary. Disregarding for the moment those peculiarities of arrangement, shape, and structure of the cells which are connected with the special work of each organ (for example, the arrangement of gland cells to form a blind tube or of the connective tissue and fibers of muscle so as to exert a pull on a bone), we may say that the typical structure of an organ would be represented in Fig. 33. The whole is surrounded by a capsule, receives a blood supply through a system of closed tubes, and contains the special cells upon whose activity its characteristic work depends. These cells are held together by a fine connective tissue whose numerous and freely communicating spaces contain a fluid, the lymph, which is free to flow out through a second system of tubes, the lymphatics. Nerves from the brain or spinal cord are also distributed in the connective tissue to the cells of the organ.

Before concluding this description of the finer structure of organs, a word may be added with regard to the physical nature of the cell substance. In its literal meaning the word "cell" is a misnomer, since it suggests a hollow space inclosed by solid partitions or walls. Plant cells do, in fact, usually have such walls around their cytoplasm (see page 116), and this cytoplasm frequently contains spaces (vacuoles) filled with a solution of salts, sugar, and other dissolved material; but neither the cell wall nor vacuoles are of universal occurrence, each being rarely found in the animal cell, and often absent even in the plant cell. Fifty years of thorough investigation has reduced the number of essential cell constituents to the cytoplasm and the nucleus, the ultimate structure of which is far from being completely understood. It would seem that the cytoplasm is a mixture of a number of materials which differ in chemical composition and in physical properties. Some are dissolved in water, making viscous solutions comparable to the white of egg or to thick or thin jellies. Others are known as *lipins*, or *lipoids* (from the Greek λίπος, "a fat"), because they resemble fats or oils in physical characters and to some extent in chemical structure; they do not mix, or mix only imperfectly, with the viscous aqueous (that is, watery) solutions, but spread over the outer surface of the cell, forming a membrane, and probably also penetrate into the cytoplasm somewhat as the connective-tissue septa of the gland penetrate the gland. These lipoid membranes would thus separate the viscous aqueous solutions of the cytoplasm into separate masses, much as the gland is divided by its septa into lobes and lobules. The lipins are supposed, among other functions, to control the passage of material into and out of the cell. The cytoplasm also frequently contains granules, one kind of which we will discuss in the next chapter as

the *zymogen* granules of the gland cells (Chapter IV, Fig. 34 and sects. 5 and 6).

The nucleus, on the other hand, is known to contain certain other compounds peculiar to itself. Some of these at times are probably in an almost solid state and appear as denser material within the membrane which usually bounds the nucleus; at other times they undergo solution, doubtless as the result of chemical changes taking place within them. There are many strong reasons for thinking that the nucleus bears an important relation to the oxidations of the cell.

CHAPTER IV

THE ORGANS AND CELLS OF THE BODY IN A STATE OF ACTIVITY[1]

The understanding of a mechanism involves more than a knowledge of its structure; we must study the mechanism in a state of activity, and the human mechanism, which we are studying, may be regarded as a factory in which some product is manufactured.

The processes employed in some manufacturing establishments consist in separating the useful constituents of the raw materials from the useless constituents, as where sugar is refined from the juice of the beet; that of others consists in producing chemical changes in the raw material, as where soap is made from fat or oil; while that of a third class consists in the application of power by machinery, as where lumber is sawed, planed, turned, or otherwise shaped into the material of which houses are constructed. The operations performed in a factory, in other words, consist in a *process of refinement*, or in the *production of a new substance*, or in the *application of power*.

The human body is a factory which presents in its activities examples of all three of these processes. A large part of digestion is a process of food refinement; out of the food we eat, the very substance of the body itself is formed; while all muscular activity, including the beat of the heart, consists in the application of power to accomplish useful

[1] An organ or cell in a state of activity is also said to be "at work." A "working" cell is one which is in action, is functioning, or is manufacturing, so to speak, some product (see footnote, p. 63).

ends. These processes are carried out chiefly by the two kinds of organs whose structure we have just studied, namely *glands* and *muscles*; and just as their structure presents a fundamental similarity of plan, so there is a fundamental similarity in the nature of their activities. This can best be made clear by a somewhat detailed study of each organ in a state of operating.

1. Physiology of the salivary glands; active glands and resting glands. The function of the salivary glands is the secretion or manufacture of saliva for use in the mouth, and one of the first things we notice about this act of secretion is that it is not constant but *intermittent*. Most organs have periods of activity followed by periods of inactivity, and these glands are no exception. Physiologists frequently speak of *active glands* and *resting glands*. We all know that our own salivary glands operate more effectively at some times than at others. The mouth waters at the sight of food; when we are in the dentist's chair the flow of saliva often seems excessive, and at other times our mouths are parched or dry.

2. The chemical composition of saliva. The saliva is sometimes thin and flows readily, while at other times it is thick and viscous, or glairy. This difference is caused by the fact that the amount of water in it varies under different conditions. At all times, however, it is a fluid which consists of water containing certain solids in solution. The amount of these solids varies from five to ten parts in a thousand of saliva, and they consist chiefly of three groups of compounds. The first is *mucin*, familiar to us as the chief constituent of the phlegm or mucus discharged from the nose and throat, and giving to the fluid its viscous character; the second group consists of substances known as *enzymes*, those in the saliva having the power of changing starch to sugar; these we shall study in detail in the chapters on digestion; the third group consists of mineral matter or

inorganic salts, of which ordinary table salt, or sodium chloride, is the most important. As we shall see, the salts and water are derived directly from the blood, while the mucin and enzymes are *manufactured by the gland.*

3. Blood supply of the active gland. Whenever a gland is actively operating there is an increased flow of blood through it. For this reason the resting gland is slightly pink, while the active gland becomes distinctly red. Since the secretion of saliva requires water and this can be obtained only from the blood, it is easy to see why an abundant blood supply is essential to activity. Other constituents of the saliva, such as the inorganic salts, likewise come directly from the blood.

4. The relation of nerves to gland work; irritability. Nerves pass, as we have seen (p. 34), from the central nervous system to the salivary glands. These nerves are essentially bundles of nerve fibers which are distributed from the brain and spinal cord to the neighborhood of the gland cells. Such fibers are the means of conveying to the gland an influence called a nervous impulse, and nervous impulses cause the gland to secrete. It is also a fact that when these nerves are cut or injured in any way, so that the gland is no longer in nervous connection with the brain and spinal cord, saliva is not secreted, even when food is placed in the mouth. Evidently the activity of the gland is normally aroused by nervous impulses from the brain and spinal cord, just as the activity of a receiving instrument in a telegraph office is aroused by the electric current which comes to it over a wire, or as a light bulb is rendered luminous by the same means. The gland stands ready for the act of secretion and is thrown into activity by a nervous impulse from the central nervous system. We speak of this action of a nerve upon the organ in which its fibers end as *stimulation* and that property of an organ in virtue of which it may be aroused by a stimulus as *irritability.*

All the active organs of the body (in contradistinction to the supporting organs, p. 41) are in this sense irritable, and most of them receive nerves through which impulses are conducted to excite their activities. Irritable tissues may, however, be stimulated by other means than by nervous impulses. Of these means an electric shock (produced by contact with wires attached to a battery) is the most familiar; others are the sudden application of heat, the presence of certain substances in the blood, and even a sharp blow.

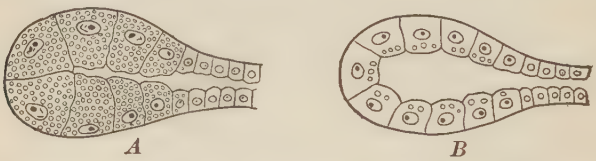


FIG. 34. Diagram showing the granules in a resting gland (*A*) and in one which has been active (*B*)

We have now to inquire what it is that happens in the gland when it is stimulated by a nervous impulse.

5. The response of the gland to stimulation by its nerve. The visible result of stimulation of the gland is the discharge of saliva into the mouth. Something must have happened in the gland which has led to the passage of water and other substances from the blood (and lymph) through the gland cells into the duct. But something more has happened, for saliva contains several substances which are not found in the blood. The gland has evidently contributed something to the saliva. How were these contributions to the secretion made?

When a gland has been resting for some time microscopic study shows that the cytoplasm of its cells becomes loaded with small granules, at times so numerous as to obscure even the nuclei (Fig. 34). As secretion goes on these granules disappear from the cells, presumably contributing something to the secretion. If the secretion continues for several

hours, it is found that the granules have disappeared and that the cell is often distinctly smaller in size than before secretion began.

The resting gland is therefore by no means an idle gland, but gradually stores within its cytoplasm something in the form of granules, which, under the influence of nervous impulses or other forms of stimulation, more or less rapidly disappears in the secretion.

6. Activity of the gland involves chemical change within its cells. It might be supposed that the granules manufactured during rest are merely dissolved or washed out of the cells in the copious stream of water and salts which during secretion passes through from the blood and lymph to the duct. If this were so, it would be possible to dissolve from the gland a substance exhibiting in general the same properties as the secretion itself. But this is not generally the case. Extracts of fresh glands commonly fail to exhibit the characteristic properties of normal secretions, although these extracts may often be changed by chemical means into the elements of the secretion. We are therefore compelled to believe that the activity of a gland means something more than the mere discharge of previously stored substances; that is to say, the material of the granules in the resting cells is not simply set free when the gland secretes, but is at the same time chemically changed. In the digestive juices, for example, we have active substances called enzymes, which, it has been shown, are derived from other substances, called *zymogens* in the gland cells. The chemical change from the one into the other is as essential to the process of secretion as is the visible flow from the duct.

These facts then present to us the picture of the cell as the active or physiological unit, as we have already seen that it is the anatomical unit of the gland (p. 37). The output of the gland is the sum of the output of its

constituent cells. During the period of rest these cells manufacture from the blood zymogens or other substances which they store away in the form of granules within their cytoplasm. When they are stimulated by the nervous impulse a chemical change takes place in them, the zymogens are changed to enzymes and other substances, and these, together with the water, salts, and other substances derived from the blood, form the secretion.

7. Physiology of muscular contraction. At first sight muscles and glands seem to differ in action or function no less than in form and structure. No two acts are apparently more unlike than lifting a weight by the muscles of the arm and the secretion of saliva by the salivary glands. But beneath obvious and important differences there are profound and fundamental similarities in the processes which occur in the two organs during activity. Like the gland, the muscle is set to work or stimulated by a nervous impulse; its contraction is accompanied by an increased blood supply; and, most important of all, its activity, or contraction, is accompanied — indeed, *preceded* — by chemical changes much more profound than that of the transformation of zymogen into enzyme. These chemical changes supply the power for its activities.

That some chemical change has taken place when the muscle contracts is proved by the fact that certain new substances then make their appearance in the muscle and may be detected in the blood flowing through it. The most important of these are *carbon dioxide*, the gas which is formed whenever wood or coal is burned, and an acid substance known as *lactic acid*. These substances were not present in the resting muscle, or else were present in very small quantities. With the act of contraction relatively large quantities of them make their appearance. They are the result of a chemical change in the muscle fibers, or cells,

precisely as the enzymes are the result of chemical changes in gland cells. Just as glandular activity produces an output called a secretion, so muscular activity produces an output consisting of substances usually described as *waste products* and *intermediary products.*

8. Waste products and intermediary products. Waste product is a term employed to designate the refuse remaining after the desirable product has been obtained; for instance, in the combustion of coal to produce heat, the waste products are ashes, cinders, and smoke. As a designation for substances formed during cellular activity, it is often misleading, since it is sometimes used to include not only materials of no further use to the cell but also some which, by further chemical changes, are utilized to contribute to the functions of the cell. The term *waste product* should be restricted to the former (*refuse*), while *intermediary product* should be employed for the latter. Accordingly, carbon dioxide, being incapable of yielding a further output of energy, is a waste product of muscular contraction; lactic acid, being further oxidized and hence utilized, is an intermediary product. It should be noted, however, that even the *true* wastes of an organ (muscle or gland) may not be refuse matter from the standpoint of the body as a whole; for example, carbon dioxide, a waste product of all cells, is a regulator of the breathing movements (p. 204).

9. The storage of fuel within the muscle fiber. The source of the carbon dioxide and lactic acid produced by the active muscle must be, on final analysis, the matter taken into the body in the form of food. After undergoing in the stomach and intestine relatively simple changes, which do not profoundly affect its chemical constitution, this food is absorbed into the blood and through this channel delivered to the cells. Thus far, however, the food material does not differ greatly from the food as swallowed. Especially to be noted

is the fact that it does not undergo sudden and profound chemical change. When, on the other hand, a muscle is stimulated to contraction, there occurs in it a chemical change requiring less than the hundredth of a second for its completion. This of course suggests the chemical change in gunpowder or dynamite. Obviously the food delivered by the blood to the muscle fiber has been transformed in the fiber into something more unstable, something capable of a very sudden chemical change. The meat, bread, butter, potatoes, and the like have been changed into something comparable to the phosphorus in a match or the gunpowder in a percussion shell. This unstable material has not been demonstrated as granules or other visible material within the cell, as have the zymogen granules of a gland; nor has it been extracted from the cell, as have mucin and enzymes; but the facts force the conclusion that, like the gland cell, the muscle fiber has used its period of rest to make and store within itself an unstable compound which undergoes upon the application of a stimulus a very sudden chemical change. This unstable compound we may call the *fuel substance* or the *fuel* of the fiber.

10. Available and reserve fuel. By *available* fuel is meant materials instantly ready to undergo the changes which result in muscular contraction; and by *reserve*, those not directly utilizable as such, but readily convertible into a form that can be used. The analogy of a machine gun[1] is useful to make clear these fundamental conceptions of muscular activity. This weapon is loaded by inserting in a slot at its breech the end of a long canvas belt provided with loops, in which are placed cartridges. These are filled with an unstable substance, gunpowder (fuel), which explodes when struck a sharp blow (stimulated). The impact of the

[1] Cheap toy machine guns are available and may be employed to illustrate the principle.

hammer, following pressure on the trigger, is the stimulus, which is followed by a sudden chemical change in the fuel. The gun goes off (contraction). The recoil (relaxation) after the explosion moves the belt, and another cartridge is brought into the proper position to be fired; then repetition of the impact of the hammer is followed by a second sudden change in the fuel and a second explosion. These acts may be repeated over and over again until the "loads" contained in the belt (available ammunition) are exhausted. In the use of the gun in warfare, additional cartridge-filled belts (reserve ammunition) are placed close at hand. If the beginning of one of these be attached to the end of the belt about to become empty, the firing of the gun may proceed uninterruptedly. The muscle similarly contains numerous "charges" of unstable substances; when a stimulus is applied, its fuel substances undergo a sudden chemical change and the fibers contract. Repetition of the stimulus produces successively the same change in the fuel, followed by contraction, until the available and then the reserve "charges" have all been used up. It is an interesting and very significant fact that even a muscle which has been removed from the body and consequently deprived of access to new supplies of fuel from the blood will exhibit contractions in response to stimuli, just as does the muscle in its natural position in the living animal. Such an excised muscle will give a long series of contractions upon the repeated application of stimuli, such as pinching with tweezers, hitting with a pencil, or touching with wires charged with electricity.

11. The chemical change of unstable fuel into waste and intermediary products involves processes of three kinds. Although our present knowledge is inadequate to the full understanding of the chemical changes in the muscle during activity, it can at least be stated that changes of three kinds are involved: namely, *oxidation*, *cleavage*, and *resynthesis*.

Oxidation is the union of the material with oxygen, one of the gases of the atmosphere. When carbon (charcoal) is burned, for example, it disappears by uniting with oxygen to form the colorless gas, carbon dioxide; when hydrogen is burned, it unites with oxygen to form water; or if a chemical compound of carbon and hydrogen (for example, kerosene) is burned, its carbon unites with oxygen to form carbon dioxide, while its hydrogen unites with oxygen to form water. Conversely, when we find that the products of any chemical change contain more oxygen proportionally than the original substance, we infer that the change is a combustion or, as it is generally called, an oxidation.

Cleavage is a process in which each molecule [1] composing the original substance is split into two or more smaller molecules. Thus new substances are formed; for example, when powdered mustard is moistened with water, each preexisting molecule of the powder yields by cleavage three different molecules (one of a sugar, one of an oil, and one of a potassium salt). The result is different from that obtained when a rock is crushed or wood is split. It is also different from oxidation, since it is effected without the addition of oxygen.

Synthesis is a reaction wherein simpler molecules are combined to form more complex ones; for instance, the molecules of oxygen and hydrogen, each consisting of two atoms, may be combined to form the molecules of water, having three atoms. As in the case of cleavage, new substances are produced but the process is reversed. We sometimes

[1] Matter is composed of *atoms* of chemical elements; these atoms are combined or bound together to form *molecules*. A lump of grape sugar, for example, is composed of an inconceivable number of molecules of sugar, and each molecule consists of six atoms of carbon, twelve atoms of hydrogen, and six atoms of oxygen bound together in chemical combination. Sugar may undergo cleavage into lactic acid by splitting its molecule of twenty-four atoms into two molecules of twelve atoms. The chemist expresses this by the following equation:

$$C_6H_{12}O_6 = 2\,C_3H_6O_3.$$

employ the term "resynthesis," when a substance originally present is re-formed, following cleavage.

All three of these changes occur in the muscle fiber during contraction. Many, perhaps the majority of, physiologists now think that the stimulus received by the muscle effects the above chemical reactions in the following order: (1) the cleavage of the unstable fuel into lactic acid and possibly other intermediary products, not yet identified; (2) the oxidation of a portion of this lactic acid to carbon dioxide and water (waste products); (3) the resynthesis of some of the lactic acid to glycogen (stored fuel).

Let us not lose sight of the central fact. The activity of a muscle fiber, like the activity of a gland cell, is the result of a chemical change within the cell. In both cases the food material derived from the blood is transformed into something else, and activity is accompanied by the production of new substances. In the case of the gland these new substances, or part of them, go to form essential constituents of the secretion, and we see at once the end secured by the chemical change. In the case of the muscle the end is, at first sight, not so clear. The substances formed are not themselves of obvious use in effecting muscular activity; but it is the energy liberated in the process of manufacturing them that serves the purpose of producing a muscular contraction.

12. Relation of the chemical changes to the muscular contraction. It is a familiar fact that chemical changes often yield power for work. The explosion of dynamite (a cleavage change), for example, will shatter large masses of rock; the oxidation of coal in a locomotive engine supplies the power to move a heavy train of cars. In both cases waste products are produced, and in the change which produces them power is liberated; but in order that this power may be utilized to do work, some mechanism is needed to apply

it to the desired end. The burning of coal in an open grate liberates power, but in the absence of any mechanism adapted to that purpose, it does no work; the same coal burned under the boiler of an engine, with its mechanism of piston, driving rod, and wheels, moves the train of cars.

In the case of the muscles, we know that the energy for the contraction is derived from their fuel substances by chemical action. We have seen that three kinds of chemical reactions take place when the muscle receives a stimulus; it has been determined, also, that heat and electricity are produced. Furthermore, we know that energy is liberated by the process of cleavage. Beyond this, all is vague. It is believed that the energy liberated in cleavage causes the contraction. Many theories have been formulated as to the specific kind of energy generated (electricity, heat, or what?) and as to the utilization or application of it so as to produce, almost coincidently with the reception of the stimulus, that shortening and thickening of the muscle fibers which characterize a contraction. To present and discuss here the various theories would only lead to confusion on the part of the student. It is sufficient to state that the phenomenon is unlike any met with in the operation of machinery and that its explanation is beyond our present understanding.

13. Heat production by the active muscle. A point of similarity between the active muscle fiber and the working steam engine should be pointed out; namely, that both produce heat. It is a familiar fact that muscular activity makes us feel warm. This is the direct result of the liberation of heat by the oxidations within the active muscle fiber. The same thing is true of the steam engine, the liberated heat going in that case to warm the engine or passing away in the gases which escape from the smokestack, steam vents, etc. It is important that the student of physiology

bear clearly in mind this feature of muscular action, since the active muscles not only supply power for the contraction but also the heat necessary to maintain the temperature of the body, and no muscle can be thrown into contraction without liberating a certain amount of heat. For a full discussion of this matter see Chapter XII.

14. The repair and maintenance of the cellular mechanism. Thus far we have considered only those chemical activities of gland and muscle cells which are directly concerned with secretion and contraction or which prepare the cell for the performance of these functions. This is only a part, however, of the functional activity of living cells, for, like all machines, cells may be injured by excessive use or by accident, and their parts (such as nucleus, cytoplasm, fibrils) must be kept in a normally active condition. Just here the living mechanism differs from the lifeless engine, for the living mechanism is itself capable of repairing damage to itself. The locomotive must be sent to the shops and be repaired by work done upon it by other machines; if the boiler rusts, it must be taken out and a new one put in: if the wheels wear unevenly, they must be made true again by turning in a lathe or new ones must be substituted; when the grate burns out, a new one must be put in its place. The living cell, on the other hand, itself makes these repairs from certain constituents of the same food out of which fuel and zymogen granules are made, and it does this by other chemical activities than those we have described and about which we possess only fragmentary knowledge at present. In picturing to ourselves the activities of these living mechanisms we must include all these chemical processes, those of maintenance and repair as well as those concerned immediately with the performance by each cell of its own special functions, such as secretion by a gland and contraction by a muscle.

15. Recapitulation. We have traced the nature of the activities of the gland and the muscle and have found that they are fundamentally the activities of the cells of which the organs are composed. The cells of other organs are similarly constructed to manifest other kinds of activity, and the character of their chemical changes and of the mechanisms for utilizing power varies accordingly; all, however, showing the same fundamental plan of machines. The body is a community of groups of cells of different kinds, each kind performing some operation more or less peculiar to itself. In addition to the two groups (gland and muscle cells) which we have studied, there are nerve cells in the brain, spinal cord, and elsewhere; cells which make blood corpuscles; cells which keep in repair the connective tissues (bone, gristle, tendon, and ligament); and many more, such as cells which manufacture or themselves form the lining of free surfaces like the skin, the alimentary tract, the air passages. The sum total, or net result, produced by these and other cells measures the activities of the body as a whole. The activity of the body — the human organism, the human mechanism — is thus the outcome, or resultant, of the action, or functioning, of its different component cells.

CHAPTER V

WORK[1] AND FATIGUE

While it is true, as shown in the last chapter, that capacity for work is one of the principal characteristics of the human body, no experience of daily life is more familiar than that work is followed by fatigue. This is true both of individual organs and of the organism as a whole; for fatigue may be either local, as when some one muscle is tired from hard work, or general, as when weariness affects all organs — those which have been resting as well as those which have been in a state of functional activity.

We use the word "fatigue" in two different senses, and it is important that a distinction be clearly made between them. (1) In one sense the word means *the diminution of working capacity due to work.* In testing one's strength of hand or of back a second test, if made immediately, shows less work done than at the first test, and this is true whether or not we are conscious of fatigue or of diminished working power. If, however, a certain time be allowed for rest, the second test will give as good results as the first. (2) In the other sense

[1] Activity on the part of a cell or organ is often referred to in physiology as "work"; for instance, the "work" of the brain, of the nerves, of the glands, of the heart, of the muscles, etc. Because this word is employed in physics for the product of force by distance ($W = F \times D$), criticism has been made of the use of the term as applied to the brain, the glands, the red blood corpuscles, etc., since in their activities there is no obvious movement of a mass of matter through space. That the muscles work is not questioned, for lifting weights through space is apparent; but even the nerve fibers do work in the strict sense, for they conduct an impulse (a form of energy) which overcomes resistance (and is therefore a force) through the length of the nerve fiber (the distance). Furthermore, all cells in a state of activity produce heat, and this heat may be measured in heat units (Calories) or work units (kilogrammeters). (See page 49.)

the word refers to the *feeling of fatigue* which frequently, though not always, accompanies the diminution of working power. We may feel tired when we have been doing nothing, and conversely, under the influence of excitement or other causes we may experience no feeling of fatigue even when we are near the limit of our working power. Often in an exciting game the players do not know at the time that they are tired or even that their working power is lessened; and stories are told of soldiers in hasty retreat who feel that they must "drop in their tracks" until the discharge of musketry close behind stimulates them to move faster than ever.

The feeling of fatigue has its seat in the nervous system, and its study must be postponed until we have learned something of the physiology of the brain and spinal cord. In the present chapter we are not immediately concerned with this side of the question, but rather with the diminution of working power produced by work. Such fatigue must be measured not by our sensations but by the work accomplished, whether that work be physical or mental. And as we studied the physiology of work in its simplest form in a single working organ, such as a muscle or a gland, so we can best begin our study of diminished working power, or fatigue, in one of these same organs, namely, the skeletal muscle.

1. Fatigue of an isolated muscle and of a muscle with intact circulation. The course of fatigue in a muscle is best studied by causing the muscle to contract to its utmost, at regular intervals of time, against the resistance of a suitable spring. If now we record the height of each contraction, we obtain a series which shows at once the effect of the work on the working power; that is, the course of fatigue. Fig. 35 gives a diagram of the arrangement of such an experiment with an isolated muscle; that is, a living muscle detached from the rest of the body. One tendon is made fast

in a rigid clamp, while the other is attached to the spring, which is stretched by the contraction when the muscle is stimulated. The length of the line written by the lever *AB* records what the muscle is capable of doing at the time; and if the records of successive contractions are made on the smoked surface of a slowly revolving drum, as in the figure, we have at once a record of the course of fatigue.

Such fatigue tracings may also be taken from a muscle within the body, and hence with its circulation intact. Thus the work of the biceps muscle in bending the arm at the elbow (Fig. 25) may be recorded by instruments essentially similar to that used with the excised muscle. In Fig. 36 we have reproduced a tracing of this kind.

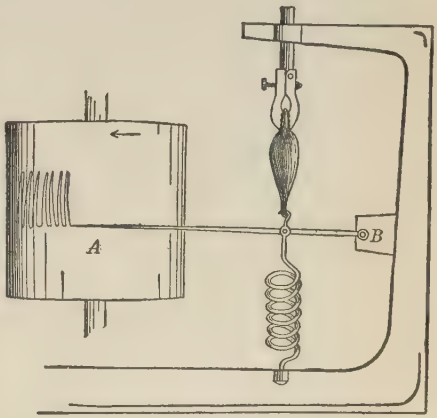


FIG. 35. Diagram of apparatus for recording successive muscular contractions

It is quite evident that a continuous line joining the highest points reached by the several contractions will represent graphically the course of fatigue, and in Fig. 37 the line *a* represents this so-called "curve of fatigue" in the experiment whose results are given in Fig. 36. It falls off at first rather rapidly, then more and more slowly, until at last it becomes parallel with the base line. In other words, the muscle in this case finally finds a constant level of working power. This may be called the *fatigue level.*

The broken line *b* in Fig. 37 gives the result of a fatigue tracing with the isolated muscle. It will be seen that the

lessening of contraction continues until at last the muscle no longer responds to stimulation. The contrast thus brought out between the effect of work upon muscles with and those without the circulation suggests that the circulation of the blood through the working organ in some way maintains the working power.

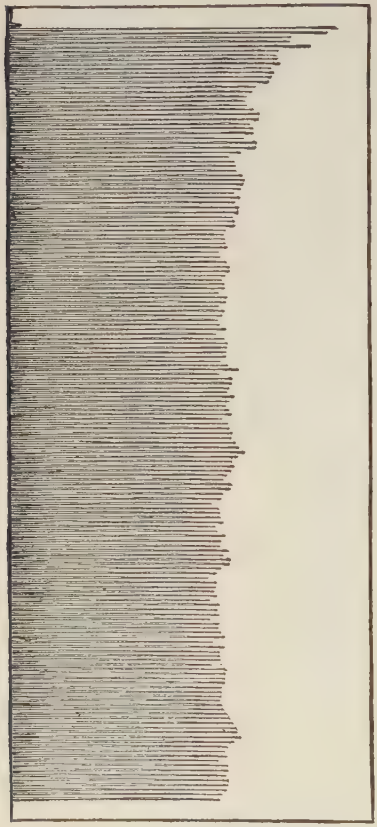


FIG. 36. Record of the successive contractions of the flexor muscles of the elbow joint

Showing the gradual decrease in working power to a fatigue level. The muscle contracted once every three seconds against the resistance of a strong spring, which was stretched each time as far as the strength of the muscle permitted

The height of the fatigue level in the same muscle at different times is very closely dependent on the rate at which the muscle works. Thus with a contraction every four seconds instead of every three seconds the fatigue level would be higher than in Fig. 36; with a contraction every second it would be much lower. When the contractions come every nine or ten seconds there is usually no falling off in the work done, the time between contractions being sufficient for the complete recovery of working power.

This picture of fatigue hardly agrees with our feeling of fatigue, for the decline of working power begins at

once, or at most after a very small number of contractions, whereas we usually notice fatigue only after work has gone on for a considerably longer time. One does not feel tired from walking, for example, during the first ten or twenty minutes of the walk. We need not discuss here just what makes us unconscious of the beginnings of fatigue; but it is important to understand that whether we are or are not aware of its presence, fatigue is the invariable and immediate result of all muscular work and indeed of all activity.

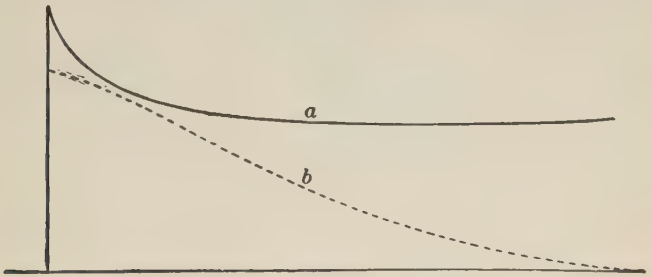


FIG. 37. Curves of fatigue

a, from a muscle with intact circulation; *b*, from an isolated muscle

Weariness is simply the conscious feeling of fatigue, but fatigue is more; it is a physical condition of living cells and organs. Moreover, its phenomena are by no means confined to muscular work. When a gland is stimulated to vigorous secretion a diminution is sooner or later noted in the amount of the secretion, and there is some reason to believe that nerve cells may also become tired from continued activity. Fatigue, then, in one word, is a natural condition of an organ accompanying work, and we may proceed to inquire into its exact cause.

2. Waste products as a cause of fatigue. When blood which has been circulating through a fatigued muscle is sent through a resting muscle, the resting muscle shows

signs of fatigue, even though it has itself done no work. Apparently the blood has extracted from the working muscle something which has the power of lessening the working capacity of a fresh muscle.

The same thing is illustrated by another experiment. A muscle which is deprived of its circulation (for example, by clamping its arteries and veins) is fatigued by vigorous work; it is then found that although when left to itself a slight recovery takes place, this recovery is much more marked if we first pass through its blood vessels a weak solution of salt. Here no food is supplied; the salt solution has only removed something from the fatigued muscle, which, in consequence of this treatment, recovers some of its working power.

Again, the mere exposure of a resting muscle to blood containing lactic acid or to blood heavily charged with carbon dioxide (CO_2) produces the condition of fatigue. Now in the last chapter it has been shown that both lactic acid and carbon dioxide are waste products of muscular activity; and these and other facts have led to the view, now generally received, that the waste products of the active organ interfere with the work of the organ and so constitute one of the main causes of fatigue. It is apparently for this reason that the injection of an extract of worked muscle fatigues fresh muscle, for the extract contains waste products. It is for the same reason that washing out a fatigued muscle with salt solution produces partial recovery, for the waste products of activity are in this way partially removed. We can also understand why fatigue always accompanies vigorous work. Waste products then necessarily accumulate and clog the living mechanism because they cannot be removed by the blood as fast as they are formed by the muscle cells. No fatigue occurs with only a single contraction every ten seconds or more, because

between contractions sufficient time is given to insure the complete removal of wastes.

3. Loss of fuel in the working muscle as a cause of fatigue. In the preceding chapter we noted that the muscle fiber stores up fuel substances, and that the explosion or combustion of these is the source of the energy for the contraction. This fuel undergoes gradual consumption during muscular activity; and, if the loss be not made good, the muscle will exhibit a diminution of working capacity (fatigue). The blood, however, not only removes the wastes but also brings new food and oxygen with which the muscle makes good the loss of fuel. Recovery from fatigue depends upon both of these beneficent offices of the blood. Accordingly, we can understand that the maintenance of a good blood supply is of the first necessity in all of our activities and that undue fatigue can be avoided only by working at a moderate rate, so that there may be (1) an ample supply of nutrition and (2) an efficient removal of wastes. It is an old and physiologically true saying that "it is the *pace* that kills."

4. Explanation of the fatigue level. In the experiment with the isolated muscle no waste products were removed nor were new food and oxygen supplied; hence the wastes in the muscle increased with each contraction, until at last their accumulation prevented all contraction. In the normal muscle the wastes likewise accumulate for a time; and this is why the curve of work at first falls (Fig. 37). It does not continue to fall, because as the wastes within the muscle increase in amount, the blood carries more and more of them away in a given time. The quantity of waste removed thus continues to increase until the same quantity is carried away from the muscle between two contractions as the muscle produces with each contraction. When this happens no further accumulation of waste is possible and the fatigue level is established.

5. General fatigue resulting from muscular activity. Everyone knows that after a day's tramp it is not simply the worked muscles which are unfit for good work, but that the brain, too, is tired, for hard mental work is then difficult or well-nigh impossible; and it is generally the fact that long-continued muscular work fatigues the brain more than brain (mental) work itself. The obvious explanation of this fact is that the waste products of muscular activity have accumulated in the blood more rapidly than the body can get rid of them, and so have fatigued the other tissues, including the nerve cells of the brain, just as the injection of the extract of a tired muscle lessens the working power of a fresh muscle. No doubt these same waste products may similarly fatigue gland cells; for experience seems to show that the secretion of digestive juices is not so active when one is suffering from muscular fatigue and that it is not wise to eat heavy meals when one is tired out. We can also understand why long-continued, vigorous muscular action produces marked fatigue in nerve cells and gland cells, while the activity of the latter produces only inappreciable fatigue in the muscles; for the amount of chemical change and the production of wastes are far greater in the case of muscular work than in that of nervous or glandular activity.

6. The analogy of the engine. In previous chapters we have compared the living body with a machine or locomotive engine; both do work, and both obtain the power for work from the chemical changes in food or fuel. What we have now learned about fatigue suggests an extension of the same comparison. Every locomotive suffers impairment of its working power with use, and special measures are taken to limit this impairment as much as possible; the gases and smoke are carried away at once by the chimney or smokestack; the furnace is provided with a grate so that the ashes shall not accumulate and shut off the draft; the bearings are

oiled and foreign matters removed; finally, as the consumption of fuel goes on, the loss is made good by stoking.

The continuance of the work of the engine requires two things — fresh supplies of fuel and the removal of wastes. Obviously the blood performs these same offices for the cell. It supplies to the cell fuel (food) from the alimentary canal and oxygen from the lungs, and it carries away the waste. Provision is thus made to maintain the human machine in working order and good condition during its activity. If the blood flows too slowly through the muscle, the same thing happens as in the locomotive when the fireman neglects to rake the fire or to put on new fuel; the efficiency both of the human engine and of the locomotive may be impaired either by the undue accumulation of the waste products of its own activity or by the neglect to supply proper food or fuel.

CHAPTER VI

THE INTERDEPENDENCE OF ORGANS AND CELLS. INTERNAL SECRETIONS

1. The products of cellular activity not necessarily harmful. We have now learned that the active living cells of the body are the seat of chemical changes which produce new substances; that the accumulation of these products of activity often limits the working power of the cells in which they are produced, and may even depress the activity of other cells to which they are carried by the blood. In the case of the skeletal muscles we have spoken of the carbon dioxide, the sarcolactic acid, and so forth, as "waste products," meaning thereby that they are incapable of serving as sources of power for the work of the muscle; and this term, together with the fact that they constitute one cause of fatigue, is apt to mislead us into supposing that they can be of no further use to the body or, even more, that they are necessarily harmful and that their presence in the blood is objectionable.

These conclusions, however, do not necessarily follow from the facts. It does not even follow that a substance which produces fatigue for that reason serves no useful purpose. Most adults can recall times when because of long-continued application to mental work or because of worry or other nervous strain they have become overexcitable and restless and have been unable to obtain the sleep of which the body as a whole stands in need. At such times sleep is often best secured by producing general fatigue through muscular work. The waste products, by their very act of fatiguing the overexcited nerve cells, may be of service to the body

as a whole; and it is probably true that not only in such abnormal conditions but also in the daily conduct of life the fatigue of moderate muscular activity contributes its share toward inducing healthful and refreshing slumber.

Thus far we have considered the chemical activities of each organ as contributing to the work of the organ in which they occur and, because of the accumulation of waste products, as the occasional cause of undue interference with efficient activity, both in the working organ and elsewhere. And yet the familiar case which we have just cited suggests another view of the matter. The products of the chemical activity of one organ may be of service to other organs, and so to the body as a whole; and while their too rapid accumulation in the blood may be undesirable, their presence in moderate amounts may be beneficial and may contribute to the normal environment of the cells of the body. This view of the case is strikingly emphasized in the physiology of the ductless glands, which we will now proceed to discuss.

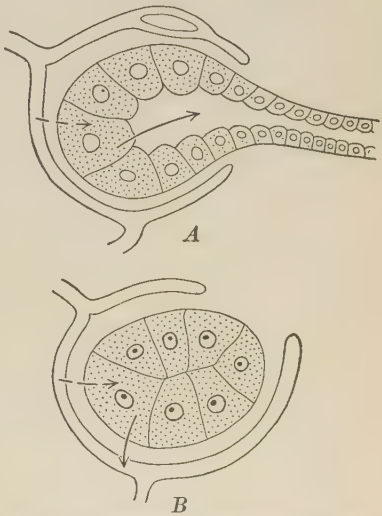


FIG. 38. Diagrams of external (*A*) and internal (*B*) secretion

The passage of food material from the capillaries into the gland cells is represented by the arrows with broken lines; the path of discharge of the secretion, in *A* into the duct and in *B* into the blood, is indicated by the arrows with unbroken lines

2. The two kinds of glands. In our study of secretion in Chapter IV we dealt with glands which discharge their principal products through a duct, either (1) into some part

of the alimentary canal, such as the salivary glands, the pancreas, and the liver; or (2) on some surface of the body, such as the sweat glands, which discharge perspiration on the skin, and the lachrymal glands, which discharge the tears on the eyeball. We must now learn that there is another kind of gland — one which, like those just mentioned, manufactures a special material from the blood, but, having no duct, discharges its products into the blood. By means of the blood alone, its secretions are carried to the parts of the body to be acted on, and often this is a remote part. This latter class of gland is called a *ductless gland* or an *endocrine organ.*

3. The ductless glands. There are a number of these ductless glands situated in various parts of the body; for instance, (1) the *pituitary body* and the *pineal gland* in the cranium; (2) the *adrenals* and the *pancreas* in the abdominal cavity; (3) the *thyroid gland* and the *parathyroid glands* in the neck; (4) the *intestinal cells* in the wall of the duodenum. It should be noted that while we speak of them as glands, this does not imply that all of them are conspicuous masses of tissue. In some cases they are separate cells lying among cells having other than secretory functions.

Knowledge of the importance of the ductless glands in the activities of the body has been gained from three main sources: (1) the observation of persons who have been deprived of these organs by accident or disease; (2) the study of persons in whom they are abnormally large or small; and (3) the administration of extracts[1] of the glands to persons of groups one and two above.

4. The internal secretions. The products manufactured and discharged by the ductless glands are called internal

[1] An extract is prepared as follows: The finely ground tissue of any gland is soaked in water to dissolve out the soluble constituents; then by filtration (straining) the nonsoluble materials are separated from the water containing the soluble constituents; the latter, which is an aqueous solution of the active constituents of the gland, is the extract, or, better, the fluid extract.

secretions, to distinguish them from ordinary secretions, which are materials that are discharged on a free surface like the skin or on a mucous membrane like that lining the alimentary canal or the respiratory passages. The active substances contained in the internal secretions are called *autocoids*. These are classified as *hormones* and *chalones*, according to whether they stimulate or depress the activities of the tissues. The functions of some of the autocoids have been carefully determined, while those of others are not definitely known. We will consider, in some detail, the ductless glands and internal secretions which are best known and refer to the others only incidentally.

5. The adrenal glands. Lying in the abdominal cavity, immediately above the kidneys, are two small glandular organs, the *adrenals*. They were formerly considered of minor importance, but are now known to be essential to the well-being, and even the life, of the animal; for when their activity has been decreased by disease there is a disturbance in the flow of blood to the parts of the body and great weakness, and when they are totally destroyed there rapidly develops a condition of extreme prostration and death. Hence, they evidently furnish something necessary to the body; and, since they have no ducts, must deliver it to the blood as an internal secretion.

There may be extracted from the adrenal glands two very active substances: *cortin* from the cortex, or outer portion, and *adrenaline* (also called *epinephrine*) from the medulla, or inner part. These are among the most potent materials used in medicine. Cortin, which has been known for only a short time, seems to specifically influence the nutrition and strength of the voluntary muscles. Its administration to animals and human beings so prostrated by disease that they can scarcely move is rapidly followed by a return of strength and a general improvement.

When adrenaline is introduced into the blood of an animal, it produces profound effects on many of the organs of the body. Among these may be mentioned: (1) a contraction of the vessels of the abdominal area, so that less blood remains in the digestive organs and more is diverted to the brain and muscles; (2) an increase in blood pressure and heart rate, so that nutriment is transported to the tissues more effectively; (3) an increase in the number of red blood corpuscles, so that oxygen is carried in larger quantities; and (4) an increase in the sugar of the blood, so that more fuel for power is available. These are all effects such as are obtainable by stimulating the sympathetic nervous apparatus as a whole; so that in this substance we have an example of a chemical stimulus which can augment or supplement the nervous apparatus.

This adrenaline is manufactured by the gland, and, during the periods of inactivity, is stored within its cells, from which it is discharged by nervous impulses. Such impulses are sent from the brain during excitement, fright, anger, and deficiency of oxygen in the tissues. All of these are conditions which call for a sudden increase in the supply of power to our muscles in order to protect us in an emergency, such as dodging cars on our crowded streets, warding off the attack of a vicious dog, or struggling for breath in balloon ascensions.

It is a very significant fact that most of the reactions of the organism to adrenaline are the very reactions which are needed in times of great muscular exertion. For example, the shifting of blood from the digestive organs to the working muscles and to the brain, rendering them more alert; the supply of increased quantities of sugar to serve as power for muscular work; the increased activity of the heart to pump more blood; the increase in the red blood corpuscles to augment the carrying of oxygen to the tissues, — all these are such reactions as would place at the disposal of the

muscles and nervous system just what is needed for quickly beginning and maintaining intense activity in case an emergency arises. It must be more than a coincidence that the action of adrenaline and the cause of its excretion should correspond with stress and the need to meet stress.

We have then in the case of the adrenals the production of a substance which is discharged into the blood for distribution to other more or less remote parts of the body, and which through its action on the sympathetic nervous apparatus coördinates the supply of oxygen and oxidizable material with the demand for more power. There is no question as to its so acting in emergencies, but there is doubt as to whether it is excreted in sufficient quantities, during ordinary undisturbed life, to play any part in the normal regulation of the oxygen and food supply to the tissues. It may be compared with a safety device which may be employed when the ordinary mechanism fails to meet an emergency — like the hand (emergency) brake on an automobile, which may be used to stop the car when the foot brake does not do so quickly enough.

6. The pancreas. This is a pale-colored gland situated in the abdominal cavity below the stomach (see Fig. 56). It is composed of two kinds of secreting cells: (1) Cells arranged in relation to a duct, like an ordinary gland. These form a secretion called the pancreatic juice, which is discharged into the small intestine. This juice contains a number of substances which act chemically on proteins, fats, and carbohydrates, so as to digest them and render them suitable for absorption. This will be considered more fully in the chapter on foods and digestion (p. 141). (2) Cells, arranged in groups not connected with a duct, which discharge an internal secretion directly into the blood stream. This product is indispensable to the life of the animal, being concerned with the utilization of the carbohydrates by the tissues.

The pancreas is then peculiar in that it is both an ordinary gland with a duct, and a gland of internal secretion having no duct. The formation of pancreatic juice and its discharge into the intestine has been well known for many years, but knowledge of the internal secretion has been accumulated only during the past two decades. The proof that the pancreas manufactures an internal secretion has been obtained in two ways: (1) By removal of the whole gland, thus abolishing both kinds of cells. In this case the animal develops a condition in which carbohydrates cannot be utilized and are rapidly excreted in the urine. As a result of the lack of this important foodstuff, there rapidly ensues loss of weight, weakness, poor general health, and finally death. (2) By ligation of the pancreatic duct, so that the pancreatic juice cannot reach the intestine. This would be equivalent to destroying the cells that discharge into the duct. While the animal with the obstructed duct exhibits some disturbances in intestinal digestion, it does not suffer from the effects of deprivation of carbohydrates as is the case when the whole gland is removed. Evidently, then, there is an internal secretion, and this is prepared by the ductless portion of the organ. This is further shown by the fact that, after the removal of the pancreas, the health and life of the animal can be preserved by grafting into its flank a piece of pancreas from another animal. In such a case, obviously no secretion could be discharged from the duct cells, since there is no opening through which it may pass.

In this connection it will be instructive to give brief attention to a disease called diabetes, in which the body fails to utilize carbohydrates and, in the same way as after removal of the pancreas, rapidly excretes them in the urine. In this disease there is weakness, loss of weight, and poor health; in fact, the condition is in every way like that observed after removal of the pancreas, except that pancreatic

juice is still formed and discharged into the intestine. This has taught us that diabetes is a disease of the ductless portion of the pancreas; that is, the diseased cells fail to produce their internal secretion, deficiency in this leads to deficiency in the use of carbohydrates, lack of the carbohydrates leads to impoverished nutrition, and impaired nutrition to weakness and other symptoms. It is like the nursery tale: "The fire won't burn the stick, the stick won't beat the dog, the dog won't bite the pig, so the old woman can't go home."

The cells which produce the internal secretion are arranged in peculiar groups, disposed here and there among the other kind of cells. These groups are called *islands* or *islets*. Examination of the pancreas of a diabetic animal shows that these islet cells are diseased. Recently there has been extracted from the pancreas of the ox a material, the administration of which will prevent diabetic symptoms from appearing in an animal from which the pancreas has been removed and also relieve the symptoms of diabetes in a human being. This material is called *insulin*, from the Latin word for "island." Since supplying it to the body will take the place of the internal secretion of the pancreas, it is believed to be the specific *hormone* of the organ. It should be understood that insulin must be employed only under the direction of a physician.

To summarize, it may be stated that certain portions of the pancreas have no duct; when this portion is absent diabetes develops, but an extract of this portion relieves diabetic symptoms by restoring carbohydrate metabolism. Therefore, the pancreas is the site of the formation of an essential internal secretion. We have here, then, the instance of an internal secretion which is essential to the liberation of the fuel to be used by other organs in the production of the heat and power needed by the body.

7. The thyroid gland. This is a small saddle-shaped organ, situated in front of the trachea and at the sides of the larynx. In normal persons it sometimes may be felt as a small mass in this location. It becomes slightly enlarged at puberty, especially in girls; and is very conspicuous and unsightly in the disease called goiter.

FIG. 39. Cross section of the thyroid gland (highly magnified)

The cells secrete into the closed sacs, which they surround, the internal secretion, which then passes out between the cells into the lymph spaces of the connective tissue

The thyroid is distinctly glandular in appearance, and we will show presently that it manufactures a material which is extremely important in the nutrition of the body. Since there is no duct, it must belong to the group of organs that furnish internal secretions.

There are recognized by physicians two distinctly opposite conditions attributable to derangements of the thyroid gland: (1) *hypothyroidism*, in which the gland is deficient or absent, and (2) *hyperthyroidism*, in which it is enlarged, sometimes excessively. These will be given brief consideration, since they throw light on the functions of the organ.

Hypothyroidism in children may be due to the fact that the gland has not developed properly, and in adults, to its having been damaged by accident or disease. In the former the condition is called *cretinism*, and there is shown a marked deficiency in the development of the body and the brain, producing feeble-minded, dwarfed individuals. We occasionally see such pygmies, actually twenty years old but in size and

intellect appearing to be children of ten years. In persons who have acquired hypothyroidism after attaining their full growth, the condition is known as myxœdema. This is characterized by laziness and sluggishness in the muscular activities and indifference and dullness in the mental. The skin loses its fine texture and the features become coarse and heavy. Feeding thyroid tissue mitigates the symptoms of both forms of hypothyroidism, which may be regarded as evidence that this gland provides some substance necessary to the welfare of the body.

Hyperthyroidism (also called Graves' disease and exophthalmic goiter) exhibits symptoms the opposite to those mentioned above. Here the individual is on the qui vive, all movements are performed quickly, and the mind is very alert. There are present also restlessness, tremor of the muscles, rapid heart beat, and a protrusion of the eyeballs. The features are sharply defined, and the skin is of delicate texture. The feeding of thyroid tissue in Graves' disease renders all the symptoms worse, while removal of a part of the gland by surgical operation may improve health. Evidently in hyperthyroidism, then, the effects noted are due to the thyroid's being too large.

Hyperthyroidism and hypothyroidism are directly opposite as regards symptoms, blood changes, and oxidative processes, estimated in terms of the quantity of carbon dioxide and heat formed in the tissues. In the former, they all show increase in activity; in the latter, decrease. This leads us to believe that the thyroid is specifically a regulator of tissue metabolism. Accordingly, when the functioning of the gland is deficient, the organism becomes inactive owing to lack of power; but when it is excessive, the animal becomes too active, owing to a superabundance of power. We may conclude, then, that the thyroid secretion coördinates the production of power with the need of power.

The hormone, or active constituent, of the thyroid gland has been isolated within recent years, and is called *thyroxin.* It produces the same effects as the thyroid extracts and may be used in the treatment of hypothyroidism. Thyroxin is a compound of iodine, and hence this mineral substance is essential to the body because it is needed in the manufacture of the internal secretion of the thyroid gland and this in turn is necessary to regulate the production of power in the organism.

The source of iodine is obviously our food materials, which have taken it out of the soil in which they grew. In most parts of the world the supply of iodine is ample, but in an occasional locality it is deficient or absent. In the latter, man and beast and fish alike suffer from hypothyroidism. This may be prevented by the feeding of iodine as sodium iodide, and it has been advocated that a small quantity of iodide be incorporated in table salt, so that iodine will always be available regardless of the food supply. For all persons, without medical advice, to use iodized salt would be dangerous, since we have noted above that an increase in the secretion of the thyroid gland is harmful to persons suffering from Graves' disease.

8. The parathyroid glands. These are four small bodies about the size of a pea, lying two in each side of the neck, between the thyroid gland and the trachea. They are composed of glandular cells not connected with a duct, which would suggest that they are organs of internal secretion. Until comparatively recently they were thought to be portions of the thyroid gland; investigators paid little attention to them, and surgeons frequently removed them during operations on the neck.

It is now known that they are highly important to the nutrition of the body, being concerned specifically with the regulation of the content of calcium salts in our tissues.

This mineral substance will be discussed in the chapter on foods and nutrition, where it will be shown that a sufficient content is essential (1) to the proper nervous control of the muscles, (2) to the hardness and rigidity of the bones and teeth, (3) to the clotting of the blood for the control of hemorrhage, and (4) to the proper exchange of fluids from the blood and lymph to the tissues. We must now learn that the amount of calcium salts in the body, and hence their beneficial effects, depend on the proper functioning of the parathyroid glands.

If the parathyroid glands are accidentally removed during a surgical operation, a condition called tetany quickly makes its appearance. This is characterized by trembling of the limbs, twitching of the muscles, and incoördination of the movements. There is less calcium in the blood than normally. In severe cases, accumulations of watery fluid in the joints and abdomen may develop. Occasionally a child is born without the parathyroid glands, or with only poorly developed ones which do not function properly. Such a child fails to grow normally, its bones and teeth are deformed, its mind does not develop, and it exhibits the symptoms of tetany.

The association of tetany with absence of the parathyroids points to these glands as being the source of some material necessary to the body. This is further evinced in the following: The effects which appear when the glands are absent may be abolished (1) by feeding parathyroid tissue or (2) by administering an extract from the parathyroid containing the substance *parathymon*, its active constituent. The relief of the symptoms is accompanied by an increase in the calcium salts of the blood.

Since the administration of calcium salts so as to increase the quantity of calcium in the blood also relieves the symptoms of parathyroid tetany and since the administration of

parathyroid preparations increase the calcium, we appear to have in the case of the parathyroids an internal secretion which specifically increases the availability of calcium to the tissues of the body. This calcium in turn serves to regulate the body in such a way as to prevent tetany. We have here, then, an instance of an internal secretion which is indispensable to the welfare of the body because it functions to conserve another substance which is indispensable.

9. The pituitary body. This is a small mass, attached to the floor of the brain. It is separable into two parts, the anterior and posterior lobes. Each of these is supposed to manufacture a different internal secretion.

Experiments seem to show that an extract of the anterior lobe accelerates growth in young animals and that the removal of the lobe retards their development. The mechanism of this action has not been worked out, but it seems to be brought about through an influence on the development of certain of the other organs of internal secretion; for instance, the thyroid. According to some surgeons, very large persons (giants), with massive joints and features have abnormally large anterior lobes while dwarfs with ill-developed features have excessively small ones. Further information is needed on the subject.

An extract has been prepared from the posterior lobe. It is called by various names, one of which is *pituitrin*. Like adrenaline, pituitrin is a very active substance, producing increase in blood pressure, in the output of urine, and in the peristaltic movements of the intestines. Some physiologists have regarded this material, or at least a very active substance separable from it, as the internal secretion of the posterior lobe, and it is supposed to exert an important regulatory influence on the nonvoluntary musculature of the body, such as the intestine and bladder. Owing to the location of the organ at the floor of the brain, it is very difficult

to remove or even examine it without seriously jeopardizing the life of the animal. Hence we lack in regard to its internal secretion such conclusive evidence as was presented in the case of the pancreas and parathyroid.

10. The duodenum. Internal secretions are manufactured not only by the cells of special glands like the thyroid, but also by specialized cells of certain organs which function most conspicuously for other ends. We have noted this in the case of the island cells of the pancreas and we meet again with the same thing in the duodenum, which is the portion of the small intestine immediately joining the stomach. In the cells lining this part of the digestive canal there is formed a substance, *secretin,* which is discharged directly into the blood stream. By the blood it is carried to the pancreas, where it, in turn, acts as a stimulus to the secretion of pancreatic juice. This chemical stimulation of the flow of pancreatic juice is one of the most interesting phenomena in physiology. It will be recalled that the products of gastric digestion are discharged into the intestine with a distinctly acid reaction, while the contents of the intestine should normally be alkaline. It is the flow of pancreatic juice which is the chief means for altering the reaction to alkalinity. Now, when acid material touches the cells of the lining membrane of the duodenum, secretin is at once formed and carried to the pancreas and the pancreas immediately responds to its stimulating action by pouring the alkaline pancreatic juice into the intestine. By this means the pancreatic juice is delivered in greatest quantity at just the time of its greatest need. It is an instance of perfect chemical coördination and is discussed in the chapter on coördination.

11. The thymus and pineal glands. The *thymus* is an organ of infancy and childhood; atrophy usually takes place by the time puberty is reached. This "gland" is situated in the thorax, just behind the breast bone. It has no duct, so if

it functions as a gland, it must belong to the group of the internal secreting ones. It is supposed to manufacture an internal secretion which is needed during the early years of life; but we have no definite proofs as to its functions.

The *pineal* gland is a small projection found in the center of the brain. Like the thymus, it is well developed in childhood but atrophies by puberty. It is supposed to exert a restraining influence, preventing abnormally rapid growth of certain parts of the body.

12. Other materials sometimes classed as internal secretions. Among these may be mentioned (1) carbon dioxide, which is formed in the oxidative processes taking place in all cells and which acts as a regulator for respiration; (2) urea, which is formed as a waste product from the proteins and acts as a stimulus regulating the action of the kidneys; (3) glycogen, which is stored up in the liver and then given off as dextrose to provide fuel for the tissues. There are many similar materials. The most important of them are more appropriately discussed in connection with the different organs in which they are formed or on which they act. For the present, it is sufficient to point out that through the medium of the blood the chemical activity of one organ may affect the life of other organs favorably or unfavorably. All the cells of the body help to make the blood what it is, many of them contributing to it something useful or even necessary to other cells. The work of the body is not merely the sum total of the work of its separate cells, each working for itself alone and performing a single function; between the cells an exchange of products often takes place, so that cells become both serviceable to and dependent upon one another for the material needed to carry out their own special chemical activities. And what is true of cells is no less true of organs; these also are interdependent, ministering to one another.

CHAPTER VII

THE ADJUSTMENT OR COÖRDINATION OF THE ACTIVITIES OF ORGANS AND CELLS

A great physiologist once said, "Science is not a body of facts; it is the explanation of facts." Some of the most important chapters of science are those which seek to explain facts so well known and obvious that we are apt to forget that they need explanation. When anything irritates the lining of the nasal cavity we sneeze; when it irritates the larynx we cough; when it irritates the exposed surface of the eyeball we wink. These three facts are well enough known; but it is safe to say that anyone considering the matter for the first time would find it difficult to explain how it comes about that anything going "down the wrong way" does not make us sneeze or wink, but sets us to coughing. The answer to the general question thus raised is the subject of this chapter, which considers the adjustment of the work of the individual cells and organs of the body, each to do its work at the proper time and so to play its due part in the work of the organism as a whole.

The more we think of it, the more wonderful does this fact of adjustment appear. The millions of living cells are in a way individual units, and communities of individuals do not invariably work together. Let us compare the human body in this respect with bodies or groups of men or boys. In a game of football each team is a body of eleven individuals, and each individual is assigned to a definite position to do definite things as occasion arises. Theoretically, under given conditions of the game it is the work, or *func-*

tion, of the "left tackle" to prevent a certain player of the opposing side from making a certain play. But there is always a doubt whether he will do this thing or "lose his head" and do something else, leaving his man free to do what he pleases. In the latter case that organism which we call a football eleven would act very much as the human organism would act if it were to wink and not cough when a foreign body lodges on the lining membrane of the larynx.

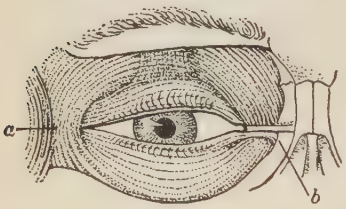


FIG. 40. The muscular mechanism of winking

Evidently we have something here to explain. Why are the actions of the body *purposeful*; that is, adapted to accomplish the right thing at the proper time? And in the more complicated actions how is the work of the different units — the organs and the cells — adjusted, or *coördinated*; that is to say, how is each one made to do its proper share of the work? Let us begin with the study of a very simple action — that of winking.

1. Winking is caused by the contraction of muscle fibers which run transversely across the eyelid in a curved course. As they are attached most firmly at the regions *a* and *b* (Fig. 40), their shortening straightens their arched course and so brings the edges of the two eyelids into contact. The work of this muscle is obviously purposeful, for the wink takes place when the eyeball needs protection; it is also coördinated, since the act is executed by a number of fibers working together, for if only those of the lower eyelid were to contract the lids could not be closed.

The muscle fibers which work together to produce the wink do not originate their own activity. They merely do what they are *stimulated* to do by the nervous impulse,

which acts upon the muscular fuel substance somewhat as a fuse acts upon a charge of gunpowder. Even the amount of contraction is determined by the strength of the nervous impulses, a strong impulse producing greater contraction than a weak impulse. In health the muscle fibers are the obedient servants of the nerves, and if they act in a

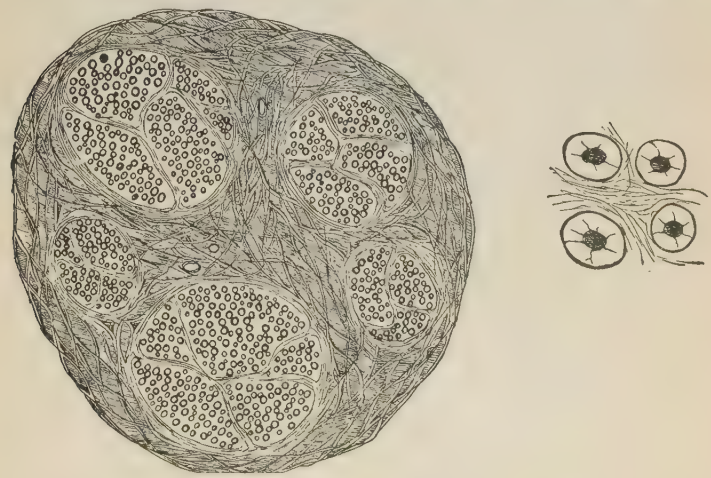


FIG. 41. Cross section of a nerve (highly magnified)

Showing five bundles of nerve fibers bound together by connective tissue containing a few blood vessels. On the right are shown four fibers more highly magnified, the dark center being the axon, around which is the white or fatty sheath, both axon and fatty sheath being inclosed within the fine membrane, the neurilemma. (Compare Fig. 42.)

purposeful and coördinated manner, it is because the nerves stimulate them to act in this way. The explanation of purposeful and coördinated action must therefore be sought, not in the muscles, but, beyond these, in the nervous system, to the study of which we now turn.

2. Structure of a nerve. A nerve, like a muscle, may be separated into long fibers (Fig. 42) which are bound together by connective tissue containing blood vessels, lymph spaces,

and lymphatics. The *nerve fiber*, which is the essential part of the nerve, just as the muscle fiber is of the muscle, differs somewhat in structure in different nerves; it generally consists of a central threadlike core surrounded by a fatty sheath, the latter being, therefore, shaped like a hollow cylinder, — which, however, is interrupted at intervals of about one millimeter, — and both of these are enveloped in a delicate membrane comparable to the sarcolemma of the muscle fiber. Such fibers are from about $\frac{1}{5000}$ to $\frac{1}{1000}$ of an inch in diameter (compare the diameter of a muscle fiber, p. 39).

FIG. 42. Four nerve fibers (highly magnified)

r, node of Ranvier, at which the fatty sheath is discontinuous

There are, however, nerve fibers which have no fatty sheath, and others which are destitute of membrane. The essential part of the fiber is the threadlike portion in the center, which conducts the nervous impulse; this is never absent from nerves and is known as the *axon*, or *axis cylinder* (Fig. 43).

3. The axon of a nerve fiber is a branch of a nerve cell. By suitable methods these axons may be traced along the nerve of which they form part and even into the brain and spinal cord; it is then found that they pursue an uninterrupted course and ultimately become continuous with the cytoplasm of a *nerve cell*. Nerve cells are found in the brain, in the spinal cord, in enlargements (*ganglia*) on certain nerves, and even alone in the connective tissue of many organs of the body, as the heart, the intestines, and other vital parts. By far the greater number are in the brain and spinal cord, and in some cases the axons to which they give rise are of very considerable length; those of the muscles of the foot,

for example, reach from cells in the sacral region of the spinal cord to the extremity of the foot. In tall persons such fibers would be over a yard long and less than $\frac{1}{1000}$ of an inch in diameter. We may regard the cell whose main

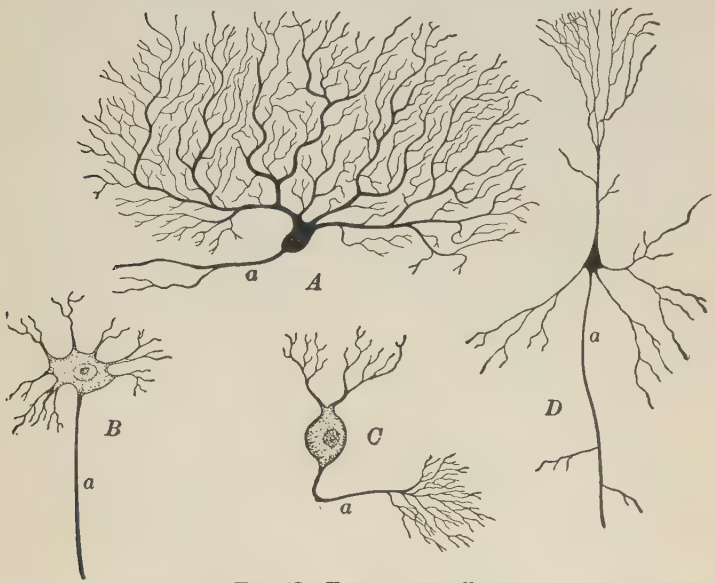


FIG. 43. Four nerve cells

A and *C*, from the cerebellum; *B*, from the gray matter of the spinal cord; *D*, from the cerebrum; *a*, the axon. The cells *A* and *D* are stained so that the main body and its axon and dendrites (p. 93) are a uniform black; *B* and *C* are stained so as to show the nucleus and the cytoplasm

portion is in the sacral cord as sending out a branch, or *process*, from this region to the muscles of the toes.

Furthermore, recent investigations have led to the generally accepted conclusion that *each axon is a part of only one nerve cell*; a single cell may give off more than one axon, but the axon is never connected with more than one nerve cell. Of these cells and of their connections with nerve fibers we

can get a more definite picture by an examination of the structure of the spinal cord.

4. Structure of the spinal cord. When the vertebral canal is opened a whitish cord is found within it, — *the spinal cord*, — from each side of which arise thirty-one nerves, or, in general, one pair for each vertebra. Each nerve has two roots, one of which arises on the ventral side of the cord, the other on the dorsal side. These roots are known respectively as the *ventral* and *dorsal*[1] *roots* of the spinal nerves (Fig. 44). On the dorsal nerve root, not far from the cord, there is a slight enlargement, or ganglion. Just outside this ganglion the two roots unite, and from their union nerves pass to the skin, the muscles, the blood vessels, the viscera, and so forth.

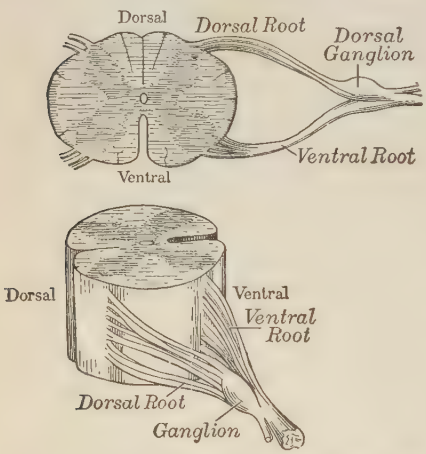


FIG. 44. The origin of the dorsal and ventral nerve roots of a segment of the spinal cord

The spinal cord itself in cross section shows a darker central core, known as the *gray matter*, surrounded by an outer lighter portion, the *white matter*. The white matter consists essentially of nerve fibers which run lengthwise of the cord and here and there send branches into the gray matter; it may be regarded as a large nerve. The gray matter, on the other hand, contains a mesh of fibers and, in addition, numerous nerve cells. There is the same difference

[1] The older anatomical terms, which even today are more generally used, are "anterior" and "posterior," instead of "ventral" and "dorsal."

everywhere between the white and gray matter of the nervous system; the arrangement in the brain is not so simple as in the cord, but here also the white matter consists of fibers running from one part of the nervous system to another, while the masses of gray matter always include collections of nerve cells.

5. Fibers of the ventral, or anterior, nerve root. These fibers may be traced into the spinal cord. It is then found that the nerve cells from which they arise lie in the gray matter in the immediate neighborhood of the root to which they belong; that is, the fibers of this root do not come from higher or lower parts of the cord or from the brain. It has been found that when fibers from this root are stimulated they throw muscles into contraction and produce effects on the blood vessels and glands, but they do not give rise to sensations or produce other effects in the cord itself. In other words, *the fibers of the ventral root conduct impulses from the cells of the spinal cord outward*; they do not conduct impulses from outside into the spinal cord. Hence they are known as *efferent* fibers (Latin *ex*, "out of"; *ferre*, "to carry").

The nerve cells from which these fibers arise consist of a mass of cytoplasm around the nucleus, and of one or more outgrowths of this cytoplasm, usually more or less branched. These outgrowths of the cytoplasm divide and subdivide, ultimately forming in the gray matter exceedingly fine terminal branches like twigs of a tree. Such processes are known as *dendrites* (Greek δένδρον, "a tree"). The nerve cells in question have numerous dendritic processes; in other nerve cells there may be but one, and still others possess no dendritic processes at all. In all cases the general appearance of the cell depends largely upon the number and manner of branching of these dendrites. Thus it happens that nerve cells from which the ventral roots arise differ

in appearance just as an oak, an elm, and a maple differ, although all show the same fundamental characteristics (Fig. 43; see also Figs. 117, 118, and 119).

In subsequent portions of this work it is unnecessary for us to go into the details of the form of the nerve cells to any extent; the student need only understand henceforward that nerve cells consist of a central mass of nucleated cytoplasm from which proceed outgrowths, or processes, which are of two kinds: (1) those which become *axons* of nerve fibers and which form an essential part of all nerve cells; and (2) the *dendrites*, which are usually but not always present. The whole structure, including the central cell body with its dendrites and axons, is an anatomical unit — a cell. To this entire cell the term *neurone* is given. The neurone is the cellular unit of the nervous system, just as the muscle fiber is the cellular unit of the muscle, and the gland cell of the gland.

6. Fibers of the dorsal, or posterior, root. The ventral root of each spinal nerve is, as we have seen, entirely efferent in function; that is, it conducts impulses only *away* from the spinal cord. The dorsal, or posterior, root, on the other hand, is found to be essentially *afferent* (Latin *ad*, "to"; *ferre*, "to carry"); that is, *its fibers carry impulses from outside toward and into the spinal cord.* This is shown by the fact that when dorsal roots are destroyed by disease, muscles can still be thrown into contraction and glands will still secrete, — that is, there is no interference with efferent impulses, — but no sensations are received from the part of the body to which these nerves are distributed; pinching the skin is not felt; the flesh may be burned and its owner suffer no pain. Since these results never follow destruction of the ventral roots, we must conclude that *impulses enter the cord solely by the dorsal roots and leave the cord solely by the ventral roots.*

It has been stated above (p. 92) that there is a ganglion on the dorsal root. Microscopic study of this ganglion shows that the fibers of the dorsal root pass through it and that each fiber gives off at right angles to itself a branch which becomes continuous with a pear-shaped nerve cell of the ganglion. These cells have no other processes. We may

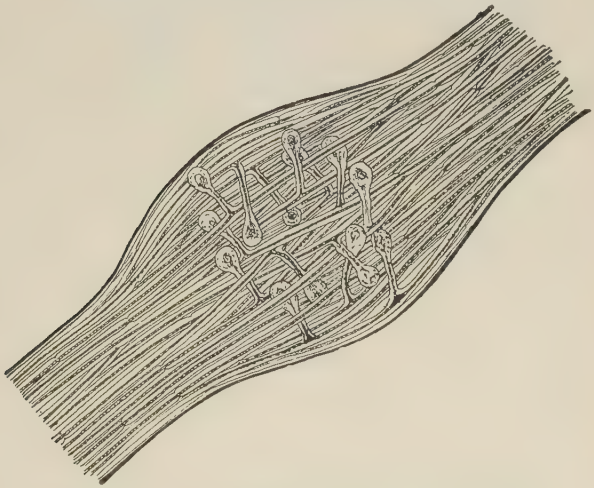


FIG. 45. Semidiagrammatic longitudinal section of a ganglion of the dorsal (posterior) root

express the relation between the pear-shaped cells of the ganglion and the fibers of the dorsal root by saying that the single axon from the main cell body divides into two in the ganglion, one branch passing outward to the periphery, the other passing centrally into the spinal cord (Fig. 45).

7. The peripheral branch of the neurones of the dorsal root, ending in sense organs. The peripheral branch ultimately ends in some *sense organ*, one of the most important of which, so far as the spinal nerves are concerned, is the skin. The eye, the ear, and the organs of smell and taste, are

other examples of sense organs, and they all contain the peripheral endings of afferent neurones. Each is sensitive to some special influence from without, as the eye to light or the ear to sound; and when stimulated they start nerve impulses moving inward along the nerves toward the brain or cord.

8. The central branch of the neurones of the dorsal root, ending in the spinal cord. The other, or central, branch passes into the spinal cord. It does not, however, like the neurones of the ventral root, there become continuous with the nerve cells of the gray matter,[1] but divides, on entering the cord, into an ascending and a descending branch (Fig. 46), each of which runs for a longer or shorter distance in the white matter of the cord. Indeed, many of the ascending branches extend as far anteriorly as the lower parts of the brain. As shown in the figure, these branches give off at right angles to themselves sub-branches (the *collaterals*), each of which enters the gray matter and ends there by breaking up into a tuft of extremely fine fibrils, the *terminal arborization*. This may be in close proximity to, and possibly in a kind of anatomical continuity with, the dendrites or the main body of a nerve cell of the gray matter, and such proximity or clasping of two nerve endings for the purpose of conveying impulses is called a *synapse*. Each afferent neurone, then, is a cell whose main body is in the ganglion of the dorsal root, and whose branches, or arms, reach out, one of them to a peripheral sense organ and the other to the gray matter of the spinal cord and brain, where it may form one or more synapses with other neurones. *By means of synapsis (contact) the afferent neurone excites or stimulates other neurones.*

9. Anatomical relation of afferent to efferent neurones. We may now put together what we have learned about the

[1] It is, as has already been pointed out, part of a nerve cell in the ganglion of the dorsal root.

neurones of the ventral and those of the dorsal root; we then obtain a plan like that shown in Fig. 46, and such, *in principle* at least, represents the manner in which the afferent neurone is brought into relation with efferent neurones.

Afferent and efferent fibers enter and leave portions of the brain in much the same way, although the separation into ventral and dorsal roots is not obvious. We may therefore

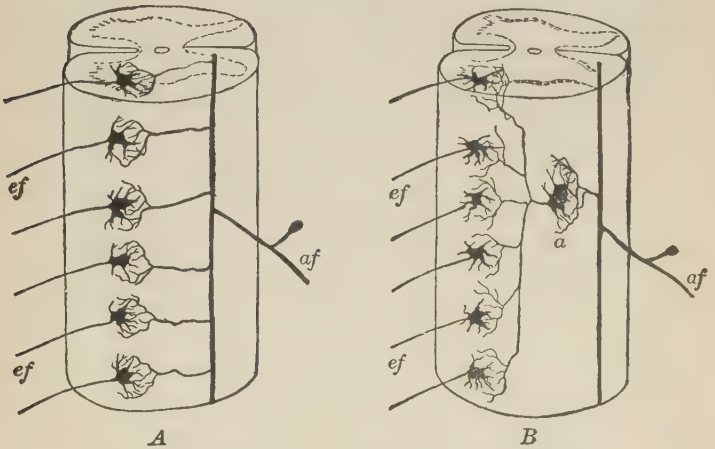


FIG. 46. Relation of afferent (*af*) to efferent (*ef*) neurones of the spinal cord

In *A* the single afferent neurone branches into six collaterals, each of which ends in a terminal arborization around an efferent cell. In *B* the connection is made through the agency of the cell *a*, as explained in section 13

take the above scheme as typical of the relation between these two kinds of neurones — those of the brain as well as those of the cord.

10. Application of these facts of structure in the explanation of purposeful and coördinated action. The diagram in Fig. 47 readily explains why the sudden appearance of an object in front of the eye causes us to wink and not cough; that is to say, it explains the purposeful character of this so-called reflex action. The formation of the image of the object on

the retina, a sense organ, starts impulses along the fibers of the afferent optic nerve; these fibers extend into the brain, and their terminal arborizations end around *and stimulate by synapsis* those efferent nerve cells which stimulate the muscles of the eyelid. The action is purposeful because the fibers of the optic nerve end around these cells and not around those which, for example, innervate[1] the muscles which open the mouth or flex the finger (Fig. 47).

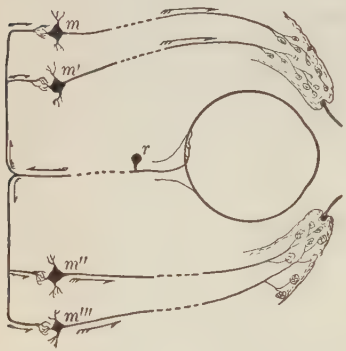


FIG. 47. Diagram of the nervous mechanism by which a wink is produced following the sudden appearance of an object in front of the eye

r, afferent neurone of the optic nerve; *m*, *m'*, *m''*, *m'''*, efferent neurones to the muscles of the eyelid

Our diagram in Fig. 46 also gives the basis of coördination — the combination of the work of different muscle fibers in orderly harmonious action. The system of collaterals on the central branch of the afferent neurone is obviously a mechanism to combine the action of the efferent neurones in this way. The diagram also gives a clue, at least, to the explanation of another element of coordination: when two or more muscles work together to accomplish a given act, one of the muscles usually works harder than another; not only must they work together, but the amount of force exerted by each must be adjusted to the needs of the movement as a whole. This adjustment is most probably effected by differences in the synapses; thus the muscle which contracts most forcibly may perhaps be innervated by the neurone whose dendrites and main cell body come into most intimate contact with the

[1] That is, supply with nerve fibers or with nerve impulses.

terminal arborizations of the afferent neurone; or the number of fibrils thus in contact may be greater in this case than in the others. These, however, are only possibilities; the whole subject requires further elucidation.

11. Definition of reflex action. An action such as we have just been studying is known as a reflex [1] action. By this we mean *an action called forth by the more or less direct action of afferent upon efferent neurones and without the intervention of the will.* The afferent neurone may be stimulated by some external agent, such as light, heat, sound, or pressure, or by some condition within the body itself, as when diseased or abnormal conditions of the stomach or some other organ induce vomiting.

It is a common error to suppose that all actions which are not called forth by the will are reflex. The essential feature of a true reflex is the more or less direct action of the afferent impulses on efferent neurones and not merely its nonvolitional character. There are, in fact, involuntary actions in which the efferent neurones are directly stimulated, not by afferent neurones, but by the condition of the blood or in other ways. Such actions are not reflex, though they may be either involuntary or unconscious or both. They are known, in general, as *automatic actions*, and we shall meet examples of them as we proceed with the study of the various functions of the body.

12. Actions resulting from stimulation by the will. A wink is not always a reflex action. We can wink "on purpose," or, otherwise expressed, a wink may be called forth by the will, entirely apart from the sudden appearance of some object in front of the eye. Here the muscles of the eyelids act in exactly the same manner as in a reflex wink, which

[1] The word literally suggests the idea of reflection from the afferent to the efferent neurones, as light is reflected from a surface; but the student has already learned enough to understand that efferent impulses are something more than mere mechanical reflections, or rebounds, of afferent impulses.

means that they are stimulated in the same way by the same efferent neurones. Thus far the mechanism is the same in the two cases, but the source of stimulation of the efferent neurones must be different.

In later chapters of this book we shall bring forward evidence to show that the exercise of the will (volition) requires the coöperation of the highest portion of the brain, or cerebrum. Nerve cells in the gray matter of the cerebrum send off axons which pass downward to those portions of the brain and spinal cord from which the motor or efferent neurones arise; with the neurones of these nerves they make exactly the same kind of connections (synapses) as are made by the afferent fibers from the retina which excite the reflex. (See Fig. 48, in which *b* is the cerebral neurone.)

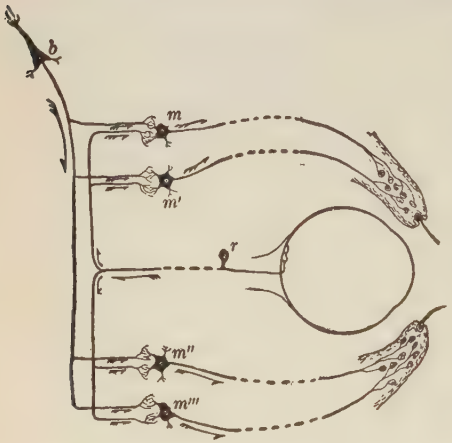


FIG. 48. Diagram of the nervous mechanism represented in Fig. 47, with the addition of the cerebral neurone *b* (see section 12)

The collaterals and terminals of such a cerebral neurone (which, it will be observed, is entirely confined to the central nervous system) simply duplicate those of the afferent neurone; hence the two neurones produce the same result.

There is, however, still a third way in which winking may be stimulated. When the cornea of the eye begins to dry, a reflex wink spreads tears over the eyeball. In this case we have to deal with a second reflex, the afferent neurones being not those in the optic nerve, but those in what is known as

the trigeminal nerve, the sensory nerve of the cornea. Our scheme thus becomes that shown in Fig. 49.

13. The "master" neurone. The multiplication of collaterals and terminal arborizations which this scheme involves would seem to be largely avoided by the presence of another neurone between those which stimulate the action and the efferent neurones which act directly on the muscles (Fig. 50).

In this way, when a wink is produced, whether from the cerebrum or from the retina or from the cornea, the single cell *a* is stimulated, and this in turn stimulates the groups of efferent neurones which immediately innervate the muscles of the eyelids. Many of the nerve fibers of the cord and brain belong to neurones which perform the same function as that attributed to the cell *a* in our diagram (Fig. 50). They are entirely confined to the brain or cord and group together those efferent cells which, by working together, produce a coördinated action. (Compare Fig. 46.)

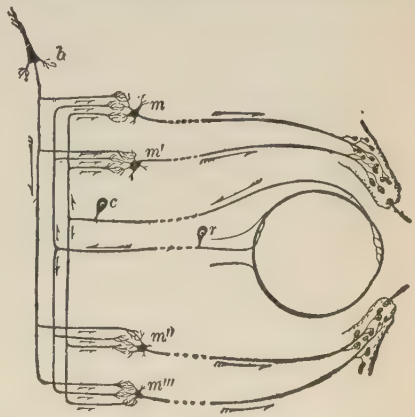


FIG. 49. The nervous mechanism shown in Fig. 48, with the addition of the afferent neurone *c*, from the cornea (see section 12)

The organization of the nervous system is, in fact, much like that of a large manufacturing establishment. The nerve cells which send axons to the muscles, glands, blood vessels, and other active tissues may be compared with the operatives, each with his special task to perform; over these are foremen, or "bosses," from whom they take their orders or, in physiological language, who stimulate them to do their

work and who would correspond to cells like *a* in Fig. 50. The foremen in turn receive orders, now from one department of the establishment, now from another, as the work of their operatives is needed in making one or the other of the products offered for sale. So the master neurones receive stimuli from the brain or from afferent nerves, as the needs or the desires of the organism as a whole require their activity. The comparison is instructive and may easily be carried out in greater detail by the student himself.

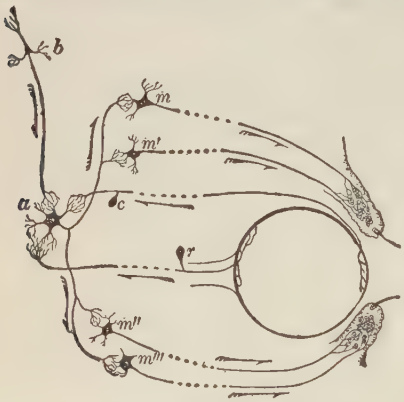


FIG. 50. The master neurone (*a*)

14. The coördination of two or more actions to achieve a definite end. These conceptions will become more definite if we study the nervous mechanisms represented in Fig. 51, which represents the combination of the wink with different physiological actions, according to the nature of the conditions which call it forth. Let us consider the two reflex winks already referred to, that from the cornea and that from the retina. The wink from the cornea is for the purpose of spreading tears over the surface of the eyeball and, to be effective, must be accompanied by a secretion of tears. We may suppose that this is accomplished, as in the diagram, by the afferent neurone (*c*) from the cornea stimulating two master neurones, one of which (m^w) produces the wink, while the other (m^t) stimulates the tear glands to secrete.

The wink stimulated from the retina, on the other hand, has the entirely different purpose of preventing the contact

of foreign objects with the cornea. For this purpose tears are not necessary and they are not secreted. But at times this wink is accompanied by a sudden starting back of the body as a whole to avoid the threatened danger. In this case we may suppose that the afferent neurone from the retina connects with the master neurones m^w for winking and m^{sb} for starting back, but that this afferent neurone does not connect with m^t, for the secretion of tears.

Finally, the volitional neurones v^{sb} and v^w, which pass from the cerebrum to their appropriate master neurones, call forth these actions of starting back or winking *as separate acts.*

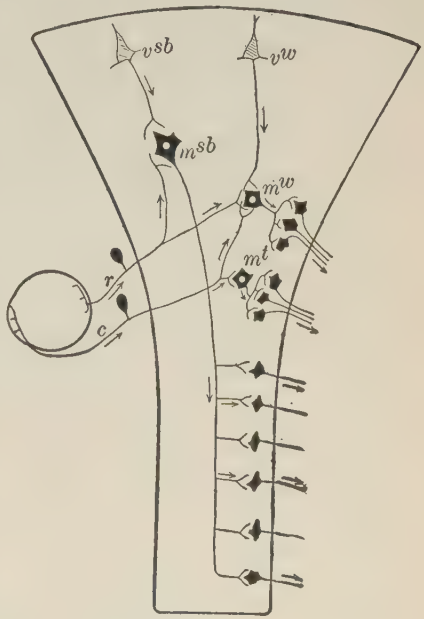


FIG. 51. Coördinations involved in the combination of the wink with other actions

In this diagram two afferent neurones, *r* from the retina, and *c* from the cornea, connect with different combinations of efferent neurones as explained in the text. Efferent master neurones are shown as follows: m^w, for winking; m^t, for secretion of tears; m^{sb}, for starting back. Neurones concerned in volitional actions are v^{sb}, for starting back, and v^w, for winking

15. The acquisition of reflexes; conditioned and unconditioned reflexes. There can be no doubt that many of these reflex mechanisms are born with us (inherited from our parents). A newborn baby, for example, like the adult, winks and secretes tears when the cornea dries; it secretes saliva when a sapid substance is placed in the mouth; it swallows when something touches the throat; a cane, if

brought in contact with the palm of the hand, is grasped firmly. These and many other reflex actions take place from the first because the baby inherits and hence is born with the complete reflex mechanism for their execution upon the application of the appropriate stimuli.

On the other hand, new involuntary reactions can be acquired in adult life, even reactions which are useless to the body. The extent to which this is true is illustrated by the following extreme case: if a piece of ice is applied to a definite spot of the skin, the amount of blood flowing through that part of the skin is greatly diminished and the skin becomes pale. This is an inherited reflex which (Chapter XII) protects the body from exposure to cold. A morsel of food placed on the tongue (where it stimulates the afferent nerves of taste) will reflexly excite the flow of saliva. In both cases we see the obvious purposeful relation between the stimulus and the reaction and in both cases we are dealing with inherited reflexes. Moreover, these two reflex mechanisms as inherited are entirely independent of each other, for the stimulation of the skin by ice does not excite the flow of saliva nor does the stimulation of the sense of taste influence the blood flow through the skin. If, however, every time that one eats, a piece of ice is applied to a certain region of skin, so that *both these reflexes are simultaneously excited*, in the course of two weeks or more it will be found that the application of ice to the skin *excites a flow of saliva even though no food is taken into the mouth.* In other words, these two reflex mechanisms have become *associated*, so that activity of the one now discharges the other. Evidently some sort of nervous connection has been established between them. Fig. 52 gives a diagram of the new association which has been established between the two centers.

The connection thus newly established between the afferent neurones of cold (*c*) and the efferent neurones to the

salivary glands (*s*) differs in several ways from the connection between the afferent and efferent sides of an inherited nervous mechanism. Such acquired reactions are not evoked with the same certainty as the inherited and, once

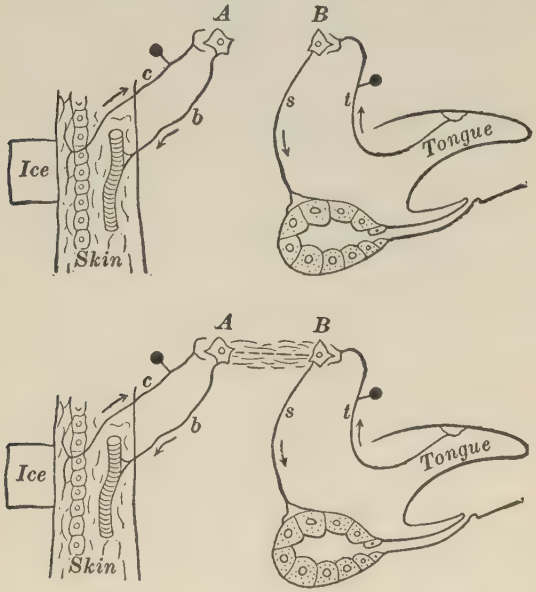


FIG. 52. The acquisition of a conditioned reflex

A, reflex mechanism for constriction of cutaneous vessels when cold is applied to the skin; *B*, reflex mechanism of the secretion of saliva when a sapid substance comes in contact with the tongue. Above is shown the usual normal condition with no connection between the two mechanisms; below, the condition after both have been repeatedly in simultaneous action

acquired, they are more readily lost by disuse. Whether we get the reaction or not depends upon the condition of the body at the time we apply the stimulus. Hence they are spoken of as *conditioned reflexes*, to distinguish them from the *unconditioned* (or inherited) *reflexes*. Undoubtedly many of our involuntary actions, especially acquired habits in

general, are conditioned reflexes acquired since birth and thus added on to the stock of inherited reflexes which make part of the equipment with which we begin life.

16. Posture and postural reflexes. A consideration of reflexes and coördination would be incomplete without a brief reference to posture and the postural reflexes. *Posture* is the attitude or position (1) of the body in respect to the perpendicular or (2) of a part of the body in respect to other parts. A few examples may be mentioned by way of illustration: prone posture, lying with the face downward; dorsal posture, lying on the back; "attention" in military tactics, standing with the body erect, the feet together, and the arms hanging at the sides; and leap-frog posture, a stooped body with the feet separated, the legs, back, and thighs partly flexed, and the hands on the knees. The position of flexion or extension of a limb is also a posture. We generally employ the term in reference to the carriage of the body, and speak of a good, natural, or hygienic posture; or of the reverse, a bad, faulty, or unhygienic posture. A good posture is one that is conducive to sound health and pleasing appearance, such as an erect body with shoulders poised above the center of gravity, chest thrust upward, and head proudly balanced.

A change in posture may be initiated consciously or unconsciously; for example, a stooping posture may be changed into an erect one or an extended limb may be flexed, as a result of stimuli originating either (1) in the brain and passing directly to the muscles concerned or (2) in sensory nerve endings of the muscles, joints, or viscera, and passing through the reflex arc. But in each case the major part of the process is completed reflexly and involves the coördination of two or more groups of muscles. This is true in walking and standing, in playing the piano, and in writing; in short, it is true in all postural relations.

The reflexes which are employed in the maintenance or change of posture are called *postural reflexes*. Like the reflexes in general, they may be inherited or acquired; but in every case they are perfected by use; and the constant cultivation of desirable postural reflexes during the period of our growth will render the maintenance of good posture and the correction of faulty posture a *habit*. For this reason, daily "setting-up" exercises, military drill, and gymnastics are invaluable aids in the establishment of health.

17. The complexity of the mechanisms of the nervous system. Such actions as we have been studying — whether the inherited reflex of winking (even when this is combined with other acts like the secretion of tears) or the acquired conditioned reflex secretion of saliva from the stimulation of the skin by cold — are comparatively simple as compared with many other actions of daily life, such, for example, as the throwing of a stone. Here not only muscles which produce motion at the shoulder, elbow, wrist, and finger joints are called into play, but also muscles which maintain the erect position and balance of the body as a whole. The entire nervous mechanism involved baffles the imagination to conceive; and yet any boy can perform the act. He can do it, however, because his motor neurones are grouped together into a perfectly well-organized army which executes at once the bidding of its commander in chief — the will.

We have given in the foregoing pages a mere glimpse into the complexity of one part of the wonderful nervous mechanism. No watch, no machine which man has ever invented or constructed, can for a moment compare with this living machine in complexity or in perfection. Yet, like all machines, this one can be abused; it can get out of order; it can even break down. And we have already learned enough to understand why this is so. Some neurones may be injured

by overwork or may degenerate from disuse; indulgence in stimulants or narcotics may poison the governing nerve cells; above all, constant failure to lead a normal life may deprive these cells of their sole means of repair. The human body is a machine designed for use, even for hard use, and it thrives upon right use; but it is a machine too delicate and too complex to be abused with impunity.

When one thinks of the hundreds, perhaps thousands, of movements which the body makes, and of the combination of these movements into definite actions or work, and then reflects that the muscle fibers which execute any movement are thrown into orderly contraction by nerve cells which are themselves commanded by higher nerve cells; that these in turn are marshaled, as it were, by still higher cells when the separate movements they evoke are to be combined into a still more complicated action — one begins to appreciate the complexity of the organization of the nervous system. The number of the nerve cells is measured by hundreds of thousands, and their efficiency in directing the working organs of the body so as to meet the demands of life depends not only upon the integrity of the neurones, but also upon the perfection of their organization, that is, their grouping into squads, companies, regiments, brigades, divisions, and corps, ready to yield instant and obedient response to the command of the higher officers of the will or to the signals of those pickets — the sense organs and their afferent neurones — which everywhere guard the outposts and give information of the need for action.

Moreover, this army of neurones, like any other army, becomes efficient by work, by drilling, by practice, even by battle. Like the soldiers of a regular army the neurones may be overworked and their efficiency as a military body may suffer thereby, but they may also work too little; the perfection of their development and of their organization

depends on the practice they get from reasonable activity. To this point we shall return; but meantime the student can safely make the application for himself. Such comparison and such application are not only instructive but intensely practical in their bearing upon the affairs of daily life — upon that right conduct of life which is the first duty of every man, every woman, every child.

18. Stimulation and coördination by chemical means. In previous chapters we have dealt chiefly with examples of stimulation of muscle and gland cells by nervous impulses, and of the coördination of the work of organs through the central nervous system; but there is another way by which both stimulation and coördination are effected. An irritable cell will respond to other stimuli than nervous impulses; among these are a sharp blow, sudden heating, make or break of an electric current, and exposure to the action of certain substances. The last is generally spoken of as *chemical stimulation.*

Among the substances produced in one organ and effecting chemical stimulation in another may be noted (1) carbon dioxide, a refuse material of the cells in general but an essential excitant for those which control the respiratory movements; (2) urea, a waste product formed in the liver but a necessary stimulus to the kidney; (3) thyroxin, a special secretion of the thyroid gland but a regulator of chemical changes in the tissues; and (4) secretin, produced by the contact of the acid products of gastric digestion with the cells of the small intestine and serving as a stimulus to the discharge of alkaline pancreatic juice. The actions of these chemical stimulants often show, in addition to the features of stimulation, an element of purposeful coördination, since they insure the proper coöperation between certain organs of the body; for example, in proportion as oxygen is used up, carbon dioxide is produced and, in turn, stimulates

the introduction of a fresh supply of oxygen by increasing the respiratory movements.

Coöperation, adjustment, and coördination are thus brought about in the body by two means: first, through chemical action; and, second, through the mechanisms of the central nervous system. The first provides for situations where no great delicacy of adjustment is required; in the secretion of the pancreatic juice, for example, it is not necessary that a definite quantity, no more and no less, be secreted; in such a muscular movement as writing, on the other hand, it is necessary that each muscle taking part shall act in a very exact manner. For such coördinations the action of the nervous system is generally necessary. Finally, as suggested by our consideration of conditioned reflexes, the nervous system is the chief means whereby we can acquire new mechanisms of coördination, thereby increasing our power of adjustment to new conditions of life.

CHAPTER VIII

FOODS AND DIGESTION

A food may be defined as being any material that we eat or drink for the purpose of maintaining our bodies in a state of efficiency. This is obviously a broad definition, including a great variety of substances, such as bread, meats, milk, vegetables, and so forth; all of which, from the standpoint of the body, are composed of mixtures of useful and useless matter. It would be better to speak of foods in the popular sense as "food materials," and to designate their useful portions as "nutrients," a term which will be explained in a subsequent paragraph (p. 113).

Before food materials, or rather their nutrients, can be made use of by the body, they must undergo certain changes to render them absorbable and utilizable by the cells of the tissues. These changes are effected in the mouth, stomach, and intestine. The process is *digestion*, which consists, in brief, of a physical and chemical separation into fragments (1) suitable for absorption from the alimentary canal into the blood vessels and (2) adapted to the needs of the living cells.

I. The Supply of Matter and Power to the Human Machine. Foods. Nutrients

1. Power and the materials for enlargement and repair supplied separately to lifeless machines. Living and lifeless machines are alike in that worn-out parts must be renewed and that power must be supplied to do work. In the lifeless machine these two requirements are supplied separately.

A factory and its equipment of machinery are kept in repair and enlarged (grow) by means of bricks, lumber, steel, belting, new pieces of machinery, and so forth, which are brought into the building, while the power which runs the machinery comes in quite separately as water power, electricity, or fuel. With the human machine this is not so.

2. Power and the materials for growth and repair supplied to the human machine in the one form of foods. Materials for the growth and repair of the human mechanism, and power for running it, are introduced from without, not separately, but together, both being supplied in the one form of food. As it does its life work the human mechanism, like a lifeless machine, not only consumes power but its parts deteriorate, and the double function of the food we eat is to make good this double loss. Some foods possibly serve only as means of power; others merely make good the loss of essential parts of the mechanism; while still others may serve both purposes.

3. Food as a source of power. Experiment and experience alike prove that foods are the source of power for work. Bread, butter, starch, sugar, beef, and the like may be dried and then burned as fuel, giving power to an engine. The occasional use of Indian corn or wheat for fuel in the West, the employment of hams and bacon as fuel by steamers short of coal, the explosion of flour dust in mills, and similar phenomena further illustrate by the teachings of experience the fact that these foods are rich in energy, or power.

When we say that food must supply power to the body, we mean that the power which it contains *must be available* to the body. A lump of coal may be a source of power, as is shown by its use in a locomotive; but a lump of coal would be of no use as food, because the body has no such means of burning it as has the engine. Again, nitroglycerin contains chemical elements needed in the food; but although

when exploded in a dynamite cartridge it may furnish power enough to shatter heavy armor plate, its energy is not available to the body.

Thus, to recapitulate, (1) food makes good the loss of living substance in the body; (2) it supplies material for growth and for the manufacture of the secretions of the body; and (3) it supplies power for the work which the body is to do. It also performs one more important function, which will be more clearly understood hereafter: (4) by its oxidation food provides the heat required to maintain the body temperature. The detailed consideration of this topic, however, must be postponed to Chapter XII.

4. Chemical composition of foods; nutrients. The human race has learned by long experience that certain things meet the demands of the body for food, and that other things do not. Perhaps no animal uses so many different materials as man in satisfying sensations of hunger and thirst. Some foods are taken from the animal and some from the vegetable kingdom, and their variety is greatly increased by special modes of preparation. But however numerous the foods from which we prepare the dishes served at different meals, chemical analysis shows that the essential constituents of all foods belong to a comparatively small number of chemical groups, and as all the members of the same group undergo practically the same processes of digestion and perform similar functions in nourishing the body, it will be equally accurate and more convenient, in treating of this part of physiology, to refer to the chemical groups, and not to the food materials containing them, such as beef, fish, eggs, butter, and so forth.

These classes, or chemical groups, are called *nutrients*. From the point of view of digestion the most important nutrients are the *proteins*, the *carbohydrates*, the *fats*, the *inorganic salts*, the *vitamins*, and *water*; and the student must

at this point become thoroughly familiar with what is meant by these fundamental terms.

5. The group of proteins. We may obtain a working idea of what a protein is by recalling some of the foods in which protein preponderates or is easily seen. Such foods are the white of egg, the lean of tender meat (muscle fibers), the curd of milk, the tenacious gluten of wheat. Proteins also exist in relatively large quantities, though not so readily seen, in yolk of egg, beans, peas, oats, and other grains.

All proteins are composed of carbon, hydrogen, nitrogen, and oxygen; some contain sulphur, phosphorus, or a trace of iron. Chemically they are exceedingly complex substances. It should be noted that the proteins are the most important nutrients which contain *nitrogen* and *sulphur*.

Many proteins readily become insoluble. Examples of this are the hardening of the white of egg or the lean of meat by cooking and of the casein or curd of milk by rennet or "junket tablets." This change is known as *coagulation*, and most of our protein food is eaten after having been coagulated in the process of cooking.

Proteins occur only within the living cells of plants and animals or as the products of these living cells. They form, as we shall more clearly see later, an essential part of the basis of the living cell and are constantly disintegrating within the cell into simpler substances. Hence there is a constant cellular loss of protein, which in the animal body can be made good only from protein in the food. Plants, on the other hand, have the power of manufacturing proteins from sugars and certain mineral salts, the latter supplying the needed nitrogen and sulphur. The plant kingdom is, therefore, in the long run the sole source of protein food for animals; for while some animals (*carnivores*) get their protein entirely by eating the flesh of other animals, the latter (*herbivorous animals*) in turn have obtained their protein from plants.

Unlike fats and carbohydrates, protein is an immediate and absolute essential of animal diet; that is to say, protein food performs certain functions in the animal body which cannot be performed by fats or carbohydrates, while the two latter nutrients perform no functions which cannot also, when necessary, be met by proteins, for a time at least. Some proteins, however, are incapable of meeting all the protein requirements of the organism, although they may meet some of them. Of these the most important in use as food is the fibrous connective tissue (pp. 11, 12), whose fibers in the uncooked state consist of the insoluble protein substance *collagen*, which by heating in the presence of water is converted into the closely related but soluble *gelatin*. Collagen and gelatin belong to the *albuminoids*, one of the subclasses of protein. The chief protein of Indian corn is similarly incapable of meeting all the protein requirements of the organism.

FIG. 53. Part of the seed of the bean

Showing the larger starch granules and the finer protein granules inclosed within the cellulose cell walls

6. The group of carbohydrates; the plant cell as a food factory. The carbohydrates constitute a very large chemical group, although comparatively few members of it (starch and sugars) are of importance as food. They are all compounds of the elements carbon, hydrogen, and oxygen, and contain no nitrogen or sulphur; those used as food are manufactured in the cells of green plants. This production of carbohydrates by the plant cell is another example of the work of cells as chemical factories, which we studied in Chapter IV. The cells of the green parts of plants, especially of the leaves, take in carbon dioxide from the air and

water from the soil, and from these plant foods, through the agency of sunlight, manufacture *sugar*, which is transported in the sap from one part of the plant to the other and is used as a source of power for plant work. The excess of sugar is converted by certain cells into *starch* and is stored in the form of small granules in the cytoplasm for future use. A potato or a grain of wheat consists of cells loaded with these starch granules. When the plant is not manufacturing sugar directly from carbon dioxide and water, its cells again transform the starch granules into sugar. The sugar in beets, apples, pears, and peaches, and in the sap of sugar maples illustrates this manufacture, storage, and transportation of sugar by plants.

FIG. 54. Section of potato
Showing starch granules inclosed within the cellulose cell walls

It will be noticed that only green plants have this power of manufacturing carbohydrates from carbon dioxide and water; hence we do not find large quantities of sugar and starch in mushrooms and other fungi. The cells of green plants, in short, are the starch factories of the world; the factories from which we purchase our supplies of starch are refineries, that is, places where starch is separated from other constituents of plant cells.

All plants, however, possess the power of manufacturing proteins from carbohydrates and certain salts, which salts they get from the soil. The carbohydrates furnish carbon, hydrogen, and some of the oxygen, while the salts furnish nitrogen, sulphur, phosphorus, and other elements. One great difference between plants and animals is this power of protein manufacture by the cells from material which is not protein. The animal cell can manufacture protein only

from protein itself or from certain decomposition products of protein. (Consult pages 122 and 263.)

7. The group of fats. Fats are familiar to us in such forms as butter, lard, the fat of meat, and olive oil. Like the carbohydrates, they are compounds of carbon, hydrogen, and oxygen, although the oxygen is present only in small quantities. They are insoluble in water, and, like the carbohydrates, they contain no nitrogen. The formula for one of the fats is $C_{51}H_{98}O_6$, and this composition is typical of all of them.

8. Oxidizable and nonoxidizable nutrients. All the above nutrients may and do combine with oxygen within the cells of the body, although the way in which this chemical union is brought about is one of the unsolved problems of physiology. While all the nutrients may be burned after being dried, such combustion requires a high temperature. Within the body they are not only burned (that is, combined with oxygen) at a temperature rarely exceeding 39° C. (100° F.), but they undergo oxidation while in a moist state or even in solution. Whatever be the process by which this oxidation is effected within the cell, there can be no doubt that it is the source of the heat for keeping the body warm and is possibly the main source of power for its activities.[1]

The remaining groups of nutrients — the inorganic salts, the vitamins, and water — are, for the most part, not oxidized in the body.

9. The groups of inorganic salts, vitamins, and water. These nutrients are absolutely necessary for the proper nourishment of the body, their presence in the blood and lymph and in the living cells being indispensable to the processes

[1] In this connection it should be noted that in addition to heat other forms of energy are produced by active cells; for instance, electricity and, in the case of the nerves at least, ultra-violet "light." These seem, however, to be the result rather than the source of the cell's activities.

of life. The salts are taken in small quantities, partly as common salt itself, partly as ingredients of the various foods we eat. They furnish much of the mineral matter of bones especially needed by young and growing animals or children; and since the body is daily losing such salts, it is necessary that they be supplied in the food. Salts, however, are not acted on to any large extent in the alimentary canal by the processes of digestion; they are largely absorbed in the same form as eaten. The same is true of water and the vitamins. The latter are organic substances of unknown composition, usually present in our foodstuffs, and necessary to the utilization of the other nutrients (p. 271). Hence the members of the groups in this paragraph do not concern us at present to the same extent as do the oxidizable nutrients, which generally have to be chemically changed, or *digested*, before they can be absorbed for use in the body.

10. Composition of some common foods. The following table gives the percentage composition of some of the more common foods (see also page 277):

	Water	Protein	Starch	Sugar	Fat	Salts
Bread	37	8	47	3	1	2
Wheat flour	15	11	66	4.2	2	1.7
Oatmeal	15	12.6	58	5.4	5.6	3
Rice	13	6	79	0.4	0.7	0.5
Peas	15	23	55	2	2	2
Potatoes	75	2	18	3	0.2	0.7
Milk	86	4	—	5	4	0.8
Cheese	37	33	—	—	24	5
Lean beef	72	19	—	—	3	1
Fat beef	51	14	—	—	29	1
Mutton	72	18	—	—	5	1
Veal	63	16	—	—	16	1
White fish	78	18	—	—	3	1
Salmon	77	16	—	—	5.5	1.5
Egg	74	14	—	—	10.5	1.5
Butter	15	—	—	—	83	3

11. Indigestible material in food. When we say that a food is digestible we generally mean that when taken into the alimentary canal, if not already in solution, it is chemically acted upon by the digestive juices so as to be *dissolved* and made capable of being *absorbed* into the blood. The greater part of the food we eat consists in this sense of digestible substances, but many foods contain a certain amount of indigestible material, and some contain a very considerable amount.

The most conspicuous example of such material is *cellulose*, a member of the same group of carbohydrates to which starch belongs. It occurs in almost all vegetable foods; and since, in the human alimentary canal, cellulose is for the most part unaffected, it cannot be absorbed and necessarily forms an important part of the feces. Other indigestible substances are the outer skin of animals (for example, the skin of fowls), and certain portions of the connective tissue of meat. Though not utilizable by the tissues, this non-absorbable matter may nevertheless fulfill the important function of distending the intestine, and thereby promote intestinal activity and prevent constipation.

12. Animal and vegetable foods. The classification of foods into animal and vegetable not only describes the origin of foods from the two great kingdoms of living things, but also defines important differences between them with reference to digestion. These differences may be summed up as follows: Animal foods are generally rich in proteins and poor in carbohydrates, while vegetable foods are generally poor in proteins and very rich in carbohydrates, especially starch. In the second place, animal foods contain relatively little indigestible material, while vegetable foods, as they occur in nature, contain large amounts of indigestible cellulose. In the third place, the digestible materials of vegetable foods (the proteins, carbohydrates, and fats) are often con-

tained within a plant cell which is surrounded by a cellulose membrane impermeable to the digestive juices; before they can be digested this membrane must be ruptured in one way or another. In the case of many animal foods, on the other hand, especially meat and fat, the cells (muscle fibers and fat cells) which contain the essential nutrients are held together by connective tissue made up largely of fibers of an albuminoid nature. These fibers are soluble in the juices of the stomach, in which the cellulose which holds together the vegetable foods is insoluble. The full importance of these differences will be evident before we have finished the study of digestion.

13. The preparation of foods for ingestion. Before corn, wheat, meat, vegetables, and other food materials can be taken into the body and made to yield up to it the material and power which they contain, they must, in most cases, undergo various preparatory or preliminary processes or treatments which will make them easier or better to eat or more attractive. The most familiar of these processes is cooking, but it is by no means the only one. In the case of animal food the animal must be captured if wild, or raised if domesticated. It must be killed, skinned, dressed, cut up, and the meat in many cases "ripened" by keeping, or "cured" by smoking, salting, drying, or corning. So, also, with plant food, such as cereals, vegetables, fruits, nuts, and the like; these must first be found if wild, or grown if domesticated. They must then be separated from the rest of the plant — threshed, if wheat, rye, oats, or barley; husked and shelled, if corn; dug up or removed from the earth, if vegetables like potatoes, celery, radishes, or lettuce. Fruits and nuts must be separated or picked from vine or tree; milk must be drawn from animals; and even salt, water, and condiments like mustard and pepper must be separated from the earth or the sea or from plants. After

collection and further preparation by winnowing, grinding, or cleaning, elaborate cooking is applied to many forms of food before it is put upon the table; and even then, at the last moment before it is eaten, a further separation, as of meat from bone, must be made either by the carver or by the eater himself.

To this entire process of the supply and preparation of food for eating, the term *alimentation* may be conveniently applied. Reflection will show that it is largely a process of *food refining*, the principal result being a concentration of the nutrients at every step. It is also a separation of the comparatively useful from the comparatively worthless (as food); and just here, and in these points — *concentration* and *the separation of good from poor materials* [1] — we may recognize a true process of digestion, but one external rather than internal: a refining in the field, the mill, and the kitchen rather than in the stomach; in the environment rather than within the organism.

II. The Preparation of Foods for the Tissues: Digestion

14. The ends accomplished by digestion. The processes of digestion accomplish three chief results: First, they separate the absorbable and therefore nutritious part of the food material from the nonabsorbable and therefore innutritious. This process, so conspicuous in the case of external digestion, is continued within the alimentary canal. Second, digestion brings the solid part of the food into solution by changing insoluble into soluble substances. This is necessary, since food is received into the body proper (that is, into the blood) through the lining membranes of the alimentary canal, and in order that it may pass through these mem-

[1] "Good" and "poor" are here used in a comprehensive sense. "Good" implies edible, wholesome, appetizing, assimilable, as well as excellent.

branes it must be dissolved. In the third place, digestion transforms the food as eaten into compounds which can be used by the cells of the body. Common cane sugar, for example, is very soluble and can be absorbed into the blood, but the cells of the body cannot use it. In the intestine it is split into grape sugar and fruit sugar, both of which can be used. Similarly, the white of egg (a protein), though soluble, would be of little, if any, use if injected unchanged into the blood; in the alimentary canal it is transformed into available compounds. It will be helpful to acquire at this time a general idea of the chemical structure of our most important foods, and of the chemical changes which they undergo in the alimentary canal.

15. The chemical structure of the starch, protein, and fat molecules; cleavage changes during digestion. The huge molecules of starch and protein are believed by chemists to consist of a large number of much smaller molecules linked together in chemical combination (see Fig. 55). When boiled in water containing acid, these large molecules undergo a very simple cleavage into their component molecules. Starch treated in this manner yields only one substance, namely *dextrose*, or *grape sugar* ($C_6H_{12}O_6$). Protein, on the other hand, yields a much greater variety of compounds, some twenty or more in number, which, though differing greatly from one another in most respects, have in common one point of structure in virtue of which they are known as *amino acids*. In the chemical laboratory amino acids are readily bound together to form *peptides*, and we speak of dipeptides, tripeptides, tetrapeptides, and polypeptides, according as two, three, four, or many amino acids enter into their formation. It is now thought that protein, as it occurs in nature, is essentially a very complex polypeptide.

In the body the enzymes of the digestive juices produce virtually the same cleavage in starch and protein as that

caused by boiling with acids, and the chemical action upon the food within the stomach and intestine consists essentially in breaking up the starch and protein into their component molecules — dextrose in the one case, amino acids

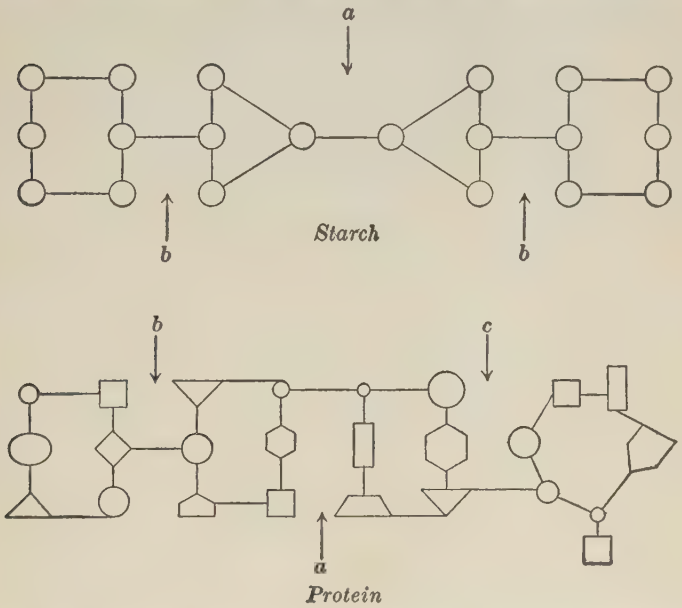


FIG. 55. Diagram of the structure of molecules of starch and protein

Starch is represented as formed by the chemical linking together of many like molecules of dextrose; protein, by the linking together of many unlike molecules of amino acids. Some of these chemical links (indicated by the arrows) are broken by cleavage more easily than others. Hence cleavage first forms smaller molecules of dextrins from starch and of polypeptides from proteins. Ultimately each may be broken up into its constituent molecules of dextrose or amino acids respectively

or small peptides in the other. We accordingly find that, as the result of digestion, the starch we eat supplies the blood (and so the body cells) with only one substance, namely dextrose (grape sugar), and the value of starch in nutrition is limited to the nutritional value of *this single substance,*

dextrose, of which it is composed. Protein, on the other hand, yields twenty or more different chemical compounds, each with its own possibilities of chemical action in the cell. Moreover, individual proteins differ in their constituent amino acids; a given protein may be entirely lacking in one or more amino acids, or it may have one or more present in very small or very large proportions. The nutritional value of the protein is consequently determined by the possibilities of chemical action of its constituent amino acids and by the quantity of each amino acid yielded by the digestive cleavage. From this we can readily understand why protein food meets a wider variety of nutritional requirements than does starch or fat; the latter yields only a few cleavage products upon digestion.

In comparison with the molecules of starch and protein, that of a fat is small and simple in construction. The fat molecule is a product of the union of glycerin with a "fatty" acid. On treatment with an alkali (caustic soda, ammonia water, or lye) the former is set free, while the latter is converted into soap. This is, in brief, the procedure employed in the manufacture of soap, castile soap being made from olive oil and caustic soda; it is also the cleavage change effected in the processes of digestion. In the intestine, the fats are attacked by the alkalies and a fat-splitting enzyme from the pancreas, the result being the preparation of smaller particles that can be absorbed. Before they reach the blood stream, however, they are reunited to reproduce a fat.

16. Digestion a chain of events. Before entering upon the study of the details of digestion in the different parts of the alimentary canal, a suggestion as to the proper point of view will be helpful. While it is true that each part of the digestive system performs functions of its own, it is also true that what takes place in one part is dependent on what takes place in others; digestion in the mouth has reference largely

to subsequent work in the stomach; gastric digestion, in turn, carries one step further the refinement of the food, which it thereby prepares for what is to take place in the small intestine; finally, the digestive processes of the large intestine are carried out normally only when preceded by the proper completion of those of the small intestine. Digestion is *a chain of events*, each one depending upon those which have gone before and, to a large extent, upon others which are taking place at the same time. The student is urged to keep this in view in the study of all the digestive processes.

A. DIGESTION IN THE MOUTH. ENZYMES

17. Stimulation of the sense of taste a reflex excitant of the flow of gastric juice. Digestion in the mouth prepares for digestion in the stomach, in the first place, by stimulating the sense of taste through the flavor of the food, for the afferent impulses thus aroused play a very important rôle in evoking the secretion of gastric juice. This point will be more fully discussed in our studies of gastric digestion. It is referred to here, in order that the student may understand that far more is to be accomplished by the stay of food in the mouth than its mastication and mixture with saliva preparatory to the act of swallowing. We might imagine a meal composed of food already well moistened and requiring no chewing, so that it could be swallowed immediately. Such a meal might have all the nutrients in the proper proportions, and yet, from the very fact that it stays so short a time in the mouth, it may not sufficiently arouse sensations of taste to evoke an adequate reflex secretion of gastric juice. It is perhaps here that we have the strongest argument against hasty eating.

18. Mastication. Digestion in the mouth prepares for digestion in the stomach, in the second place, by the com-

minution, or grinding down, of the food in the act of chewing. When this is properly done the larger food masses are broken up into smaller ones, so that the whole is made more readily accessible to the subsequent action of digestive secretions. The small intestine has almost no means of accomplishing this subdivision of the food; the stomach can do it for some foods easily, for others with difficulty, while against others it is virtually powerless. Only in the mouth can all foods be thoroughly comminuted. For this reason it is necessary to keep the teeth sound.[1]

19. Chemical action of saliva. Digestion in the mouth presents a feature which is characteristic of all the digestive processes; namely, a combination of the mechanical action of some form of muscular movement with the physical and chemical action of some digestive juice. The muscular act of chewing, and the secretion of saliva, which moistens and acts chemically upon the food, coöperate to reduce the food to smaller particles and to change part of it into other substances. Neither mastication nor insalivation, acting alone, would be as effective as are both when acting together. We shall see the same thing more strikingly illustrated in our studies of gastric and intestinal digestion.

The chemical action of saliva is much less important than that of other digestive juices, but it is typical of the character of all of them, so that it is profitable to consider it at some length. Upon proteins and fats saliva has no action whatever, but upon starch it exerts a striking and readily demonstrable influence. To demonstrate the effect in question some starch paste should be prepared. This is not a clear solution, like salt or sugar, but an opalescent liquid, which does not become clear by passing through ordinary filter paper. A characteristic test for starch — the blue color

[1] The structure and care of the teeth will be described in Chapter XXIII.

produced when a few drops of a solution of iodine [1] are added to it — may be used to detect its presence in the following experiments:

EXPERIMENT I

Two test tubes or small beakers containing starch paste are prepared. Collect some saliva and boil half of it. To one portion of the starch paste add the boiled saliva (after it has again cooled to the room temperature); to the other add the unboiled saliva. Mere observation will show that while the first test tube remains opalescent, the second soon becomes clear. A few minutes after this change has occurred, a little of the second starch-saliva mixture may be removed, diluted with water, and tested with iodine; the color produced is no longer pure blue, but purplish; that is, a mixture of red and blue. Some minutes later the iodine test gives a port-wine red color, and still later no color at all. This change of reaction is due to the fact that the saliva has changed the starch into dextrin, which gives the red color, and then has changed the dextrin into a substance which gives no color with iodine.[2] Meanwhile the starch in the first test tube shows no change, either in its opalescent appearance or in its original blue reaction with iodine.

Boiling the saliva has destroyed its power of acting on starch, and it is known that this is due to the fact that the heat has destroyed the enzyme, known as *ptyalin*, or salivary diastase, which has the power of changing starch to sugar.

EXPERIMENT II

Let us now inquire what has become of the starch in the second test tube. The solution is clear and has a sweetish taste. Moreover, if boiled with a mixture of sodium hydroxide and a few drops of copper sulphate, it gives a red precipitate, indicating the presence of sugar. These simple tests, then, prove that saliva first changes starch into dextrin and subsequently changes dextrin into sugar.

[1] Made by dissolving a few flakes of iodine in alcohol or in an aqueous solution of potassium iodide.

[2] The cleavage of the starch molecule does not take place by splitting off successive molecules of dextrose, but by splitting into two molecules, each, let us say, approximately half as large as the original molecule. By some such process first one *dextrin*, then another, successively appears. Continuation of the cleavage ultimately gives a substance, *maltose*, which consists of two molecules of dextrose bound together. Finally, the maltose is split into two molecules of grape sugar. We speak of the dextrins and maltose as *intermediate products*, and of the dextrose as the *end product*, of the cleavage.

EXPERIMENT III

Dilute some starch paste with an equal volume of 0.4 per cent hydrochloric acid (which will, of course, make a 0.2 per cent solution of the acid). Now add a few drops of saliva. It will be found that no reaction takes place. Saliva will not act in an acid medium of this strength, and it can be easily shown that it acts most vigorously in a neutral or faintly alkaline medium. This result is of much practical importance, because the gastric juice contains approximately 0.2 per cent of hydrochloric acid and may therefore be expected to interfere with salivary digestion.

EXPERIMENT IV

Prepare five or more small beakers of starch paste and add (best with a medicine dropper) to the first a drop of filtered saliva, to the second two drops, to the third three drops, and so on; then observe the time required in each case for the disappearance of the opalescence and also of the iodine reaction. This experiment will show that while a very small amount of saliva will transform an indefinite amount of starch into sugar, the more saliva there is present the more rapidly will the transformation occur; and the same thing is true of all enzymes. If the result is not perfectly clear with the undiluted saliva, repeat, but use saliva diluted two or three times with water.

While we are eating, the food obviously stays too short a time in the mouth to allow the conversion of any large amount of its starch into sugar before it is swallowed. Whatever actual work the saliva may do in bringing about this chemical change must evidently be done chiefly in the stomach, and this will be studied in the next section.

We have dwelt at length upon the enzyme action of saliva, not merely for its own sake, but rather because the behavior of the salivary juice is typical of the action of other digestive juices and of enzyme action in general. All the other juices of the alimentary canal, with the single exception of the bile, contain enzymes, and it will greatly help our understanding of the digestive action of these enzymes if that of the salivary enzyme be first mastered.

Digestion in the mouth, then, consists first of a mechanical process of chewing, by which food is crushed or com-

minuted; second, of a physical process of moistening, by which dry foods are prepared for the act of swallowing; and, third, of a chemical process, the chief part of which is the conversion of starch into sugar by enzyme action. In addition to this the stimulation of the sense of taste reflexly starts the secretion of the gastric juice, which now becomes the main chemical agent in carrying on the work of digestion. To the consideration of the digestive processes in the stomach we may now devote our attention.

B. DIGESTION IN THE STOMACH. GASTRIC JUICE

According to popular ideas the stomach is the chief organ of digestion; in fact, however, it is an organ in which the food which has been swallowed is temporarily stored while undergoing a preliminary preparation for the more important changes which are to take place in the intestine. In this preparatory process, to be sure, some of the food is incidentally changed into those forms in which it passes into the blood, but this action is incidental and subordinate to the main function.

20. Form and structure of the stomach. The stomach is a large pouch into which open two tubes — the esophagus (gullet) toward the left side and the intestine on the right (see Fig. 56). The two ends of the pouch are different in structure and are known as the *cardiac* (left) and *pyloric* (right) portions of the stomach; the cardiac portion differs from the pyloric portion in having greater diameter and thinner walls. The entire inner surface is lined by a *mucous membrane* some three or more millimeters in thickness, crowded with comparatively simple glands which pour their secretion, the *gastric juice*, into the stomach very much as sweat glands discharge perspiration on the skin (see Fig. 57).

This glandular membrane is one of the two principal components of the stomach wall; the other is the muscular or contractile tissue, which forms a second coat outside the other and closely united to it by connective tissue containing the larger blood vessels, lymphatics, nerves, and so forth.[1]

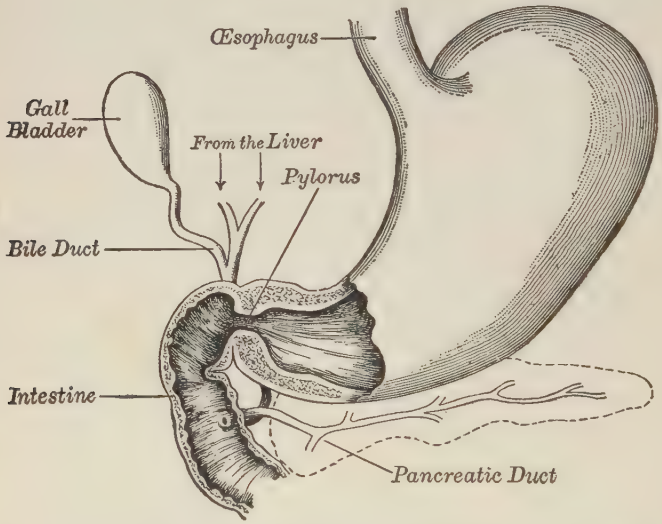


FIG. 56. Stomach, beginning of small intestine, and entrance of bile duct and pancreatic duct

During digestion the bile flows directly from the liver into the intestine; at other times the opening of the bile duct is closed and the bile passes into the gall bladder, where it is stored

The muscular coat consists of three layers of nonvoluntary muscle fibers, arranged severally, in circular, longitudinal, and oblique directions. Furthermore, this coat is comparatively thin in the cardiac region and comparatively thick in the pyloric, the thickening in the latter region being caused chiefly by the circularly arranged muscle fibers.

[1] Fig. 63 (the large intestine) shows somewhat the same arrangement of mucous and muscular coats as exists in the wall of the stomach.

21. The gastric juice. The gastric juice is a clear, thin liquid which contains, among other things, about 0.2–0.3 per cent of hydrochloric acid and certain enzymes. The quantity secreted per day is estimated at from 2 to 3 quarts. Upon starch it has no action whatever, nor has it any action on fats, unless the fat is in the form of an emulsion (that is, very fine drops of oil suspended in water, as in milk or mayonnaise dressing); indeed, the very limited power of gastric juice to attack fat is a matter of considerable importance in dietetics. Its main chemical action is upon the proteins, which under its influence undergo cleavage into *proteoses* and *peptones*. The proteoses and peptones, like the original protein, are polypeptides (p. 122), but of smaller molecular size than protein. They are not coagulated by heat, and most of them are soluble.

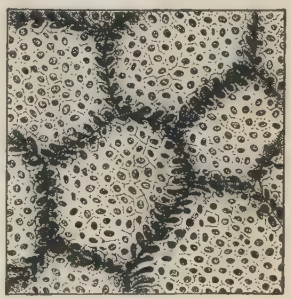


FIG. 57. The inner surface of the stomach (magnified about 20 diameters)

Showing the openings of the glands. The glandular lining membrane is thrown into folds

EXPERIMENTS

Prepare some artificial gastric juice as follows: To one quart of water add 7 or 8 cc. of concentrated hydrochloric acid, and to this a little active pepsin, which may be obtained at any drug store. Pepsin is extracted from the stomach and is the most important of its enzymes. A solution of pepsin in the given strength of hydrochloric acid is virtually gastric juice. Try the effect of this on the following substances by placing each in a half-tumblerful of the juice. To get the complete effect the mixture should be set aside for twenty-four hours and tests made the next day. Observations should be made during the first hour or two. If the digesting mixture can be kept in a warm place (90°–100° F.), the action will be more rapid and the results more satisfactory. The digestions can best be carried out in corked 4-ounce bottles, which should be shaken occasionally to secure better contact of the digestive juice with the material undergoing digestion.

1. The white of soft-boiled egg (boiled 3–4 minutes). This is composed mostly of protein; it will be dissolved. Into what is the egg white changed?

2. A piece of tendon, which can be obtained from any butcher. This is composed of the kind of fibers which are found in the connective tissues holding the cells together (see Chapter III). The tendon first swells, then gradually disintegrates, its protein (albuminoid, p. 115) fibers going into solution. A small residue will be left.

3. A piece of lean, rare meat cut or chopped into small pieces. The meat will disintegrate, owing to the solution of its connective tissue fibers; then the protein muscle fibers will go into solution, being changed into soluble peptides.

4. A piece of lean, well-cooked meat. The result will be much like that in (3) except that it will probably take longer to bring the muscle fibers into solution.

5. Some jelly (made from gelatin) which has set. This will be gradually dissolved.

6. Some fat (not gristle) of beef. The mass will disintegrate for the same reason as in the case of meat. The fat itself will be unacted on, but will rise to the top, where it may form a layer of fat or oil.

7. A piece of bread. This consists of starch, fat, and other ingredients, held together by the tenacious gluten (a protein). As the gluten is dissolved by the gastric juice the undissolved residue is set free.

8. Some starch paste. No action.

9. Some fried steak. Note the prolongation of the period of digestion.

Instructive experiments may also be made with cheese, sweetbreads, potatoes, peas, or other foods. They would all bring out the main points in the action of the gastric juice. These may be summed up as follows: Gastric juice has no effect upon pure fats (although it plays an important part in the digestion of adipose tissue[1]), nor upon carbohydrates, such as starch or sugar. Its part in digestion consists in its action upon the proteins of the food and especially upon those proteins (albuminoids) which make up the connective tissue of animal foods. By dissolving this connective tissue,

[1] The fat of meat consists of connective tissue whose cells are greatly swollen with drops of fat. In typical adipose tissue the connective-tissue cell becomes one large fat droplet surrounded by the thin layer of the cell cytoplasm with its nucleus. These "fat cells," like the muscle fibers of meat, are thus held together by the fibers of connective tissue and are set free when the latter are digested and dissolved away by the gastric juice (see Figs. 94–96).

which holds together the muscle fibers, fat cells, and other constituents, animal food is considerably subdivided and made to present a greatly increased surface to the further action of digestive juices. It is also well to remember that the gastric juice dissolves connective tissue much more rapidly than does any other of the digestive juices and that this action upon connective tissue is really more important than that upon other proteins, although the latter is usually more emphasized. Other proteins not acted on in the stomach are rapidly digested by the pancreatic juice in the intestine; connective tissue, on the contrary, escaping solution in the stomach, is dissolved but slowly in the intestine.

The student is, however, warned against supposing that because gastric juice is able to transform the proteins of the food to peptides, it actually does exert this action upon all the protein eaten. In point of fact, as protein foods are divided into smaller and smaller particles in the stomach, they are discharged into the intestine, where their digestion is completed by the pancreatic juice. *In man the pancreatic, and not the gastric, juice is the main agent of protein digestion.*

22. The stomach at work. Having now gained a general idea of the chemical changes which occur in the stomach, we may proceed to consider what actually happens when food enters that organ. And here our knowledge has been gained partly by examining the gastric contents at different periods of digestion, partly by observing the movements of the stomach by the aid of the Röntgen rays, and partly by other means (Fig. 58).

As soon as food enters the stomach, and even while it is still in the mouth, the gastric glands begin to discharge the gastric juice, and continue to do so during the four or more hours of gastric digestion. When the meal is fluid or is small in amount, this gastric juice is thoroughly mixed with it; when, however, the food is more or less solid and bulky, only

the outer layers, which are in immediate contact with the walls of the stomach, are mixed with the juice. At least this is true at the cardiac end; the cavity of the pyloric portion is so small and the amount of movement there so great that all portions of the pyloric contents are thoroughly mixed with gastric juice; in the much larger cardiac portion the central mass of the food may receive no gastric juice and thus may remain, for an hour or more after the meal, neutral or alkaline in reaction. Under these circumstances very considerable amounts of starch may continue to undergo the salivary digestion begun in the mouth.

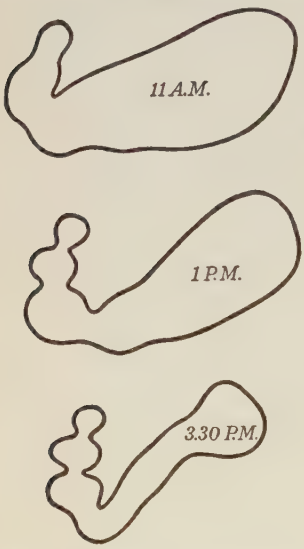


FIG. 58. Outline of the contents of the stomach of a cat at three stages in the digestion of a meal eaten about 11 A.M.

Showing the peristaltic constrictions which pass over the pyloric portion, and the diminution of the quantity of food in the cardiac end. (Full description given in section 22)

Any chemical action is aided by agitation, since the reacting compounds are thus brought into more intimate union; and observation of the working stomach shows that while the cardiac portion makes no movements, but merely keeps up a steady contraction and thereby exerts a moderate pressure upon its contents, the pyloric portion executes, from a very early stage of digestion and throughout the whole process, a series of contractions which gradually bring about a thorough mixture of the contents and rub down the softened food into smaller and smaller masses. These contractions consist of rings of constriction which arise at the beginning of the pyloric portion and pass onward to the

pylorus itself, a new ring beginning about once every ten seconds and consuming from thirty to forty seconds in passing to the pylorus. Consequently there are always two or more slowly moving rings in the pyloric end of the stomach at one time.[1]

The pyloric end of the stomach is thus the seat of a combined chemical and mechanical action on the food. The vegetable foods are softened, while the connective tissue of the animal foods is dissolved away; in addition, the food is mixed with a considerable amount of liquid supplied by the secretion of gastric juice. The contents of the pyloric end of the stomach thus ultimately come to consist of *minute solid masses suspended in a liquid,* the consistency of the whole being that of moderately thick pea soup. This product of the work of the stomach is known as *chyme.*

23. The expulsion of chyme into the intestine. The openings of the esophagus and intestine into the stomach are usually closed; the former is opened normally only during the act of swallowing, while the latter opens at irregular intervals during the process of gastric digestion. The opening of the pylorus allows the rings of constriction moving over that region of the stomach to discharge the semifluid chyme into the intestine. If, however, a large mass of solid food arrives and is driven against the walls, the pylorus reflexly closes, thus guarding the entrance of the intestine from the passage of food not yet ready for intestinal digestion. The pressure exerted by the sustained contraction of the walls of the cardiac end of the stomach adds to the food in the pyloric region new portions from time to time, and the same combined chemical and mechanical process already described is continued until the whole mass is reduced to chyme and driven into the intestine.

[1] These movements are well shown in models, which may be obtained from the Harvard Apparatus Company, Back Bay Post Office, Boston.

This brief sketch of the working of the stomach shows that this organ serves the two main functions of storing the food and of making it more accessible to the digestive fluids of the intestine. When the chyme is delivered to the intestine, the mechanical difficulties in the way of absorption are practically gone; the surface of the food exposed to digestive action is now immensely increased by its subdivision, and the work remaining for the intestine is almost wholly the *chemical* duty of changing the constituents of the chyme into substances which are soluble and ready for absorption.

Serious troubles arise when, for one reason or another, gastric digestion goes wrong, because the subsequent processes of digestion are largely dependent upon the preparation which the food receives in the stomach. Gastric digestion may be impaired in one of three ways: first, the gastric juice may not be secreted in proper amount or proper strength; second, the stomach may not execute its movements efficiently; third, the gastric juice secreted may not be able to get at the food readily, owing to improper cooking or insufficient mastication. The study of the conditions which produce these troubles — which taken together constitute one form of *indigestion*, or *dyspepsia* — will be postponed to the chapter on the hygiene of eating (Part II).

24. The stimulus to the secretion of the gastric juice. The first requirement for the work of the stomach is the secretion of sufficient gastric juice. Of late years the brilliant researches of physiologists have shown that the secretion of gastric juice is called forth in three ways:

1. *The "psychic" secretion.* When agreeable or appetizing food is offered to an animal, and especially when such food is taken into the mouth, a secretion of gastric juice follows, which may continue for fifteen minutes or more. This secretion occurs when the food has been in the mouth only ten or fifteen seconds and even when it is merely seen or smelled

by a hungry animal and not taken into the mouth at all. Again, it occurs only when the animal is conscious; for if food be introduced into the stomach of a sleeping dog, it evokes only the most scanty secretion of gastric juice after the animal has awakened. Moreover, both the amount and the efficiency of the juice secreted vary directly with the enjoyment of the meal. When meat is given to a dog which is not hungry, no such abundant secretion of gastric juice occurs as during hunger.

It is clear that we have here to deal with a nervous process more complicated than the simple reflex, and that the efferent discharge to the stomach occurs as the result of nervous processes taking place in the brain in connection with the *enjoyment* of food. In other words, the more the food is desired or enjoyed, the more efficient will be this secretion of the gastric juice.

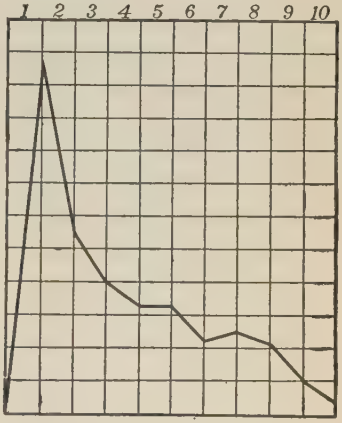


FIG. 59. The curve of the psychic secretion of gastric juice

Vertical lines represent half-hour periods after taking the meal; horizontal lines, relative amounts of gastric juice secreted

It is known that this psychic secretion will continue for several hours after an ordinary meal, increasing in amount during the first hour or more and gradually diminishing from that time onward (Fig. 59).

2. *Stimulation of the stomach by constituents of certain foods.* We have seen that the direct introduction of food into the stomach (for example, into the stomach of a sleeping animal) does not of itself evoke a secretion of gastric juice. Some foods, however, contain substances which do evoke such a secretion, the most important of these being certain

constituents of meat. Bouillon, for example, which is an extract of meat, directly excites the wall of the stomach to secrete. This is a reason for introducing the soup early at a course dinner. Meat extracts and meat juices are the most effective food constituents for this purpose; milk and water are far less effective, while most foods, notably bread and white of egg, have no such effect at all.

3. *Stimulation of the stomach itself by the products of protein digestion.* Although the mere contact of most foods with the lining of the stomach does not evoke a secretion of gastric juice, yet it is known that after digestion has been begun by the action of the psychic secretion, certain of the products of protein digestion arouse a second secretion by acting directly on the lining of the stomach. This second secretion increases in amount as the first (or psychic) secretion diminishes, and continues throughout the remaining period of gastric digestion.

To sum up: The secretion of the gastric juice is initiated by a complicated series of nervous processes connected with the enjoyment of the food while it is being taken and masticated; this is aided to some extent by direct stimulation of the lining of the stomach by a few food constituents, notably extracts of meat. The gastric juice thus secreted acts upon the proteins of the food and produces from them digestive products which directly stimulate the stomach to secrete and, in fact, maintain the secretion to the end of the period of gastric digestion. Without the psychic secretion the proteins are not digested fast enough to induce sufficient subsequent secretion; without the stimulus of the products of protein digestion the psychic secretion does not suffice to complete the digestion of a hearty meal — a labor which may require four or five hours.[1]

[1] The psychic secretion is probably an unconditioned reflex from the mouth, reënforced by a conditioned reflex involving the cerebrum; the stimulation by the products of protein digestion is probably due to a hormone (p. 75) liberated in the mucous membrane of the pyloric region.

C. DIGESTION IN THE INTESTINE. PANCREATIC JUICE. BILE. INTESTINAL JUICE

Every few minutes during the process of gastric digestion the pylorus opens and the stomach forces a few cubic centimeters of chyme into the intestine. Chyme, which consists of water holding in solution certain products of digestion, and carrying in suspension larger quantities of undissolved matter, has the consistency of moderately thick pea soup. The suspended matter consists, among other things, of small bundles of muscle fibers (from meat), fat melted by the heat of the body and set free from adipose tissue by the digestion of its connective tissue, bits of coagulated protein, such as casein from milk or the white of egg, together with starches, fats, and proteins of animal or vegetable foods. Thus far the digestive processes in the mouth and stomach have been essentially preparatory to the *main chemical work of digestion, which takes place in the small intestine.* The finely subdivided food is now attacked by the digestive juices of the small intestine, brought into solution, and otherwise made ready for absorption into the blood.

25. The general structure of the intestine; the pancreas and the liver. The main functions of the intestine, like those of the stomach, are indicated in the structure of two of its coats, the muscular coat and the glandular mucous membrane. The fibers of the former are arranged in two layers — an inner layer, disposed circularly (see Fig. 60), and a much thinner outer layer, disposed lengthwise. The contraction, or shortening, of the circular fibers constricts the bore, or lumen, of the tube, and this constriction of the intestinal tube is the most important work of the muscular coat. Sometimes the constriction is confined to one place; at other times it moves along the tube, pushing the contents before it. (See under Peristalsis, p. 147.)

In the structure of the inner or mucous membrane two points are of importance to us. In the first place, numerous simple tubular glands discharge into the intestinal tube an important digestive juice, the *intestinal juice*; in the second place, fingerlike processes, or *villi* (0.5–0.7 mm. long by 0.1 mm. thick), arise from its surface and project into the intestinal cavity (Fig. 61). These are important organs of absorption. The entire surface of the villi, the glands, and the remaining surface of the intestine between these structures is lined with a continuous membrane composed of columnar cells, which separates blood vessels and lymphatics in the intestinal wall from the cavity of the intestine (see Fig. 57). The products of digestion must therefore pass either through these cells or between them to enter the blood or lymph.

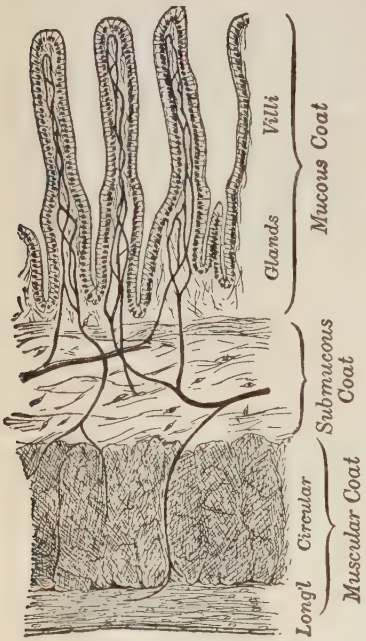


FIG. 60. Longitudinal section of the small intestine

The submucous coat consists of connective tissue and contains the larger blood vessels from which the mucous and muscular coats are supplied with blood

The intestine is some twenty or twenty-five feet in length, and the intestinal glands (Fig. 60) constantly secrete intestinal juice upon the contents as they are slowly moved along the tube. Two other juices are added to the intestinal contents almost immediately after their entrance into the upper part of the small intestine. These are the pancreatic

juice and the bile, which are secreted, respectively, by the pancreas and the liver. The entrance of the ducts of these glands is shown in Fig. 56. It is not necessary for our present purpose to describe the minute structure of these organs; it is enough for the student to understand that they are glands (p. 34) which pour their secretions through ducts into the intestine very much as the salivary glands pour their secretions into the mouth.

26. The mechanism of secretion of pancreatic juice, bile, and intestinal juice. The mechanism which evokes the secretion of the pancreatic juice has already been described (p. 85). It will be recalled that the lining cells of the duodenum (that part of the intestine immediately beyond the pylorus) contain a material which, when acted upon by the hydrochloric acid of the chyme, is transformed into the hormone *secretin*. This is absorbed into the blood and chemically excites the pancreas to secrete.

The secretion of bile by the liver is continuous, although it is greater at one time than at another. Circular muscle fibers at the mouth of the bile duct close the opening into the intestine when bile is not needed there; at such times the bile secreted accumulates in the gall bladder. During active digestion the mouth of the bile duct remains open and the bile flows directly into the intestine.

Little is known of the factors determining the secretion of intestinal juice, but it probably is continuously secreted, at least so long as food is in the intestine. Thus each consignment of chyme from the stomach receives its share of pancreatic juice and bile soon after it enters the duodenum, and then subsequently receives continuous additions of intestinal juice as it is passed along the intestinal tube by the action of the muscular coat presently to be described.

27. The pancreatic juice is a strongly alkaline liquid and consequently, when mixed with the acid chyme, neutralizes

most, if not all, of the hydrochloric acid of the chyme. Thus it happens that while the food in the stomach is strongly acid, in the intestine it becomes at once more nearly neutral or even alkaline. Since pepsin acts only in an acid medium, the gastric juice now becomes inactive and is soon destroyed by the pancreatic juice, so that it plays no further rôle in protein digestion. This is henceforward carried on by an enzyme of the pancreatic juice, *trypsin*, which acts most vigorously in a neutral or slightly alkaline medium. It forms from the proteins of the food the same general class of peptone-like substances produced by the action of the gastric juice, but carries this cleavage further into smaller peptides and even to some extent to the constituent amino acids. Trypsin continues the digestion of proteins begun by pepsin. Indeed, in some cases the preliminary action of pepsin is necessary, since trypsin does not act so readily upon the original protein as it does upon the earlier products of peptic digestion; upon these cleavage products, however, its action is most vigorous.

In addition to trypsin the pancreatic juice contains at least two other important enzymes. One of them, *amylopsin*, is practically identical with the ptyalin of the saliva and changes starch into sugar much as happens in salivary digestion. The other enzyme, *lipase*, acts upon fats, changing them into fatty acids and glycerin. We cannot go into the details of the somewhat complicated digestion of fats. The change, like that of proteins into peptones and of starches into sugar, involves the formation of a smaller molecule, either of fatty acids or soaps, or both, and it is probably in these forms that fats are received from the intestine by the villi.

The pancreatic juice thus contains a special enzyme for each of the three great classes of nutrients — proteins, fats, and carbohydrates — and thoroughly completes their diges-

tion after they have undergone the preparatory processes effected by cooking, mastication, and gastric digestion. *Pancreatic juice is by far the most important of the digestive juices in producing the chemical changes of digestion.* In this respect, also, we may say it is of primary importance in the work of intestinal digestion, the other two juices, the bile and the intestinal juice, acting as aids in its work.

28. The bile contains no enzymes of importance in digestion. It is in fact partly an excretion, some of its constituents being waste products which are poured into the intestine only to be ultimately discharged from the rectum. Other constituents of the bile play an important rôle in the digestion and absorption of fats, as is shown by the fact that if bile be prevented from entering the intestine, from 40 to 60 per cent of the fat eaten fails of absorption and is discharged with the feces. It is probable that this is because certain soaps formed in pancreatic digestion are not soluble unless bile is present. When these soaps are not dissolved, they are not only themselves not absorbed, but, by being precipitated and adhering to other still undigested food, prevent ready access of enzymes and hence greatly retard digestion.

29. The intestinal juice contains two kinds of enzymes, one acting on protein products, the other on carbohydrate material. The former class, represented by the single enzyme *erepsin*, has no action on the proteins of the food, but splits peptones and other products of gastric and pancreatic digestion into very small peptides and amino acids. A similar thing is true of the carbohydrate enzymes — they have no action on starch nor on dextrins (p. 123), but disaccharides (that is, sugars formed by the chemical combination of two simple sugars, as dipeptides are combinations of two amino acids) are readily split into their component simple sugars. Cane sugar (*sucrose*) and milk sugar (*lactose*) are two carbo-

hydrate foods which belong to the disaccharides; a third is *maltose*, which is the stage in the cleavage of starch preceding the final separation into its component molecules of grape sugar (*dextrose*). These *inverting enzymes* insure the complete cleavage of the larger carbohydrate molecules into their component sugars, precisely as erepsin insures the complete cleavage of the large protein molecule into its component amino acids or smaller peptides.

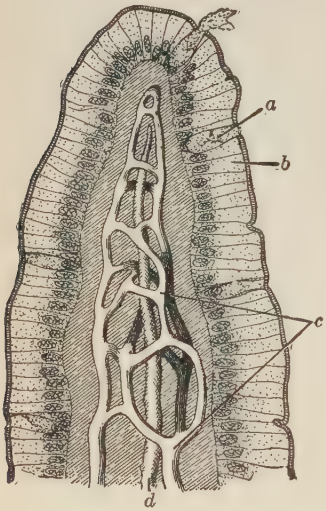


FIG. 61. Longitudinal section of the tip of a villus

Showing the columnar lining cells *b*, through which the products of digestion must pass on their way to the blood vessels and lymphatics. The connective tissue between the columnar cells and the vessels is indicated diagrammatically and without showing its structure. *a*, a cell which manufactures mucus; *c*, capillaries; *d*, lacteal, or lymphatic

Another most important character of the intestinal juice is its large content of alkaline salts, especially sodium carbonate (soda). Two processes constantly occurring in the intestine produce acid; these are (1) the splitting of the fats into fatty acids and glycerin by lipase, and (2) the bacterial decomposition of carbohydrates and (to some extent) of proteins. The sodium carbonate of the intestinal juice, which, it will be remembered, is being secreted along the entire length of the intestine, neutralizes these acids and so maintains the reaction of the contents at an approximately neutral point. This reaction is most favorable for the action of the enzymes present. The combination of sodium carbonate with fatty acids, moreover, forms soaps, which are more

TABULAR SUMMARY OF THE CHEMICAL PROCESSES OF DIGESTION

FOODS	ENZYMES	ORGANS SECRETING ENZYMES	PLACE OF ACTION OF ENZYMES	INTERMEDIATE CLEAVAGE PRODUCTS	FINAL (OR END) PRODUCTS OF DIGESTION
Protein foods	Pepsin	Stomach	Stomach	Proteoses	Peptides
	Trypsin	Pancreas	Intestine	Peptones	Amino acids
	Erepsin	Intestine	Intestine	Peptides	
Starch	Ptyalin	Salivary glands	Mouth	Dextrins	Maltose
			Cardiac end of stomach		
	Amylopsin	Pancreas	Intestine		
Cane sugar	Inverting enzymes	Intestine	Intestine		Glucose + fructose
Milk sugar	Inverting enzymes	Intestine	Intestine		Glucose + galactose
Maltose	Inverting enzymes	Intestine	Intestine		Glucose
Fat	Lipase	Pancreas	Intestine		Glycerin
					Fatty acids
					Soaps

readily soluble than the fatty acids. In this way no doubt the products of fat digestion are more promptly absorbed than would otherwise be the case.

30. Action of the muscular coat of the small intestine. The object of the movements of the intestine is not the grinding down of the food into smaller masses, but, in the first place, the agitation of the digesting mixture so that, on the one hand, good contact is secured between food particles and digestive juices, while, on the other hand, the products of digestion are quickly brought into contact with the villi for absorption; and, in the second place, the slow movement of the food onward in the intestinal tube. To accomplish these ends there are two kinds of intestinal movements.

31. Divisive, or segmenting, movements. The food is not distributed continuously along the entire length of the intestine, but is subdivided into a number of separate portions which lie in different loops of the tube. This is partly explained by the intermittent character of the discharge of the chyme from the stomach. The number of these portions varies at different times, but may be as many as twenty or even more. These masses of food undergo division into small segments, produced by a series of constrictions of the walls, as shown in Fig. 62. The next moment these are replaced by a second series of constrictions between the first. Each segment is thus divided into two, and the neighboring halves of these segments fuse. The next moment the second series of constrictions is replaced by the first, and this process continues at times for many minutes *with no change in the general position of the food mass*. These divisive, or segmenting, movements occur from twenty to thirty times a minute, and it has been estimated "that a slender string of food may commonly undergo division into small particles more than a thousand times while scarcely changing its position in the intestine."

32. Peristalsis. Every now and then a ring of constriction, instead of being confined to one place, moves onward, pushing the contents of the tube before it for a short distance (two or more inches). A contraction of this kind is called peristaltic. The effect produced is much the same as when

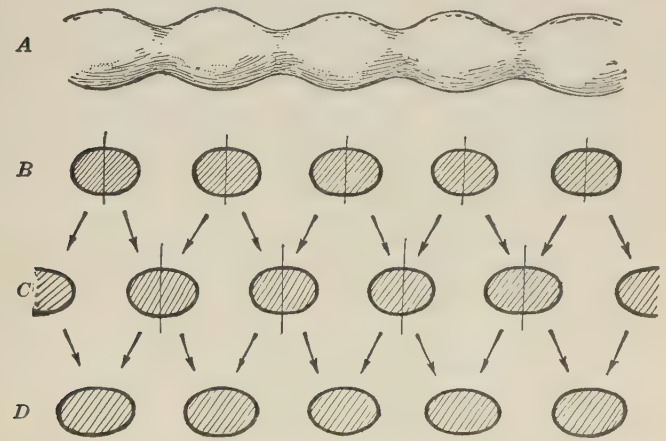


FIG. 62. The divisive, or segmenting, movements of the small intestine

A, surface view of a portion of the intestine, showing six constrictions which divide the contents into five segments, as shown in *B*; as these constrictions pass away, new ones come in between them and divide each segment of the contents into two, the adjoining halves of neighboring segments fusing to make the new segments shown in *C*. Repetition of this process results in the condition shown in *D*

the contents of a rubber tube are emptied by squeezing them along between the thumb and one of the fingers.

Thus each consignment of chyme delivered from the stomach immediately receives its share of pancreatic juice and of bile; and the final transformation of the digestible foods takes place as the whole is driven from time to time along the intestine by peristaltic contractions, the efficiency of the contact of the food with the digestive juices, as well

as its exposure to the absorbing surfaces, being greatly enhanced by the agitation produced by the movements of constrictive division carried out by the circular muscles between periods of peristaltic activity. *The efficiency of digestion and absorption depends as much on the movements carried out by the muscular coat as on the chemical processes effected by enzymes and other constituents of the digestive juices. Digestion is always a result of coöperation in chemical and mechanical work.*

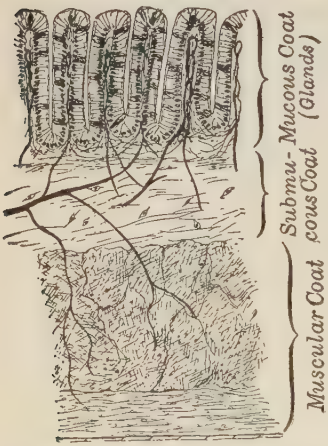


FIG. 63. Longitudinal section of the large intestine

Note the absence of villi

So far as is known, these movements are aroused by the distention of the intestine with food and possibly by chemical stimulation of the muscular coat by substances formed within the tube. The presence of solid indigestible material also favors the movements.

33. Digestion in the large intestine. The large intestine contains no villi, and its glands secrete an intestinal juice characterized by a large content of mucin (p. 50).

In the small intestine the amount of water added by secretion balances that absorbed, so that the consistency of the contents undergoes but little change from the stomach to the beginning of the large intestine. This consistency, it will be remembered, was (approximately) that of moderately thick pea soup. During the passage through the small intestine the digested portions of the food are being removed by absorption, while the indigestible elements are left behind. Among the indigestible elements of food are

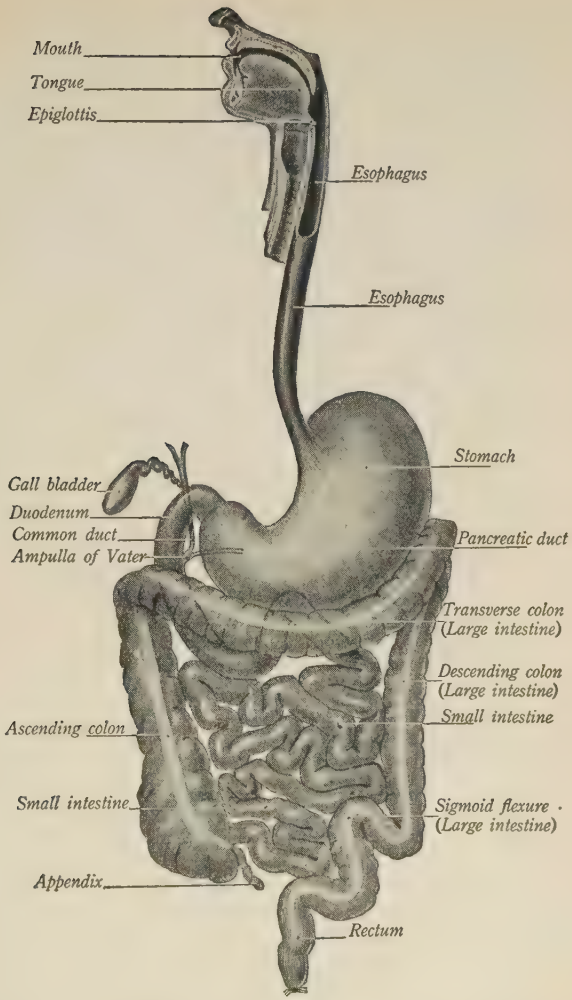


FIG. 64. The digestive system

This illustration enables one to visualize the course along which food travels in its many stages of digestion, absorption, and elimination

certain connective tissues of the animal foods, but especially cellulose (p. 119), which forms the cell wall of plant tissues. The large intestine receives from the small intestine this indigestible material, together with a certain variable but comparatively small proportion of the proteins, fats, and carbohydrates which have thus far escaped digestion; in addition there are certain constituents of the digestive juices which are not absorbed, and some (for example, certain constituents of the bile) which are distinctly excretory products.

Special provision seems to be made to insure the approximately complete digestion and absorption of proteins, carbohydrates, and fats before the food enters the large intestine. The opening from the small into the large intestine is guarded by a circular muscle, the *ileocolic sphincter*, which ordinarily regulates the passage of food out of the small intestine much as the passage of food from the stomach is regulated at the pylorus (p. 135). In this manner considerable accumulations of material may occur at the end of the small intestine and remain there for two hours or more while the combined action of enzymes and segmenting movements completes the digestion and absorption of the nutrients. Recent work indicates that this material is discharged periodically into the large intestine by a relaxation of the ileocolic sphincter and a vigorous peristalsis in the terminal portion of the small intestine. It would also seem that this discharge is especially apt to occur when food is taken into the stomach, as a reflex to this discharging mechanism. Obviously the end attained by such delay is the more complete digestion of the food in the small intestine.

Reference to Fig. 64 will show that the large intestine consists of four parts, the ascending, transverse, and descending colons and the rectum, there being an S-like bend

FIG. 65. Action of the muscular coat of the large intestine, as shown by X rays. After Hertz

The lower border of the ribs and the upper border of the pelvis are sketched. Black shadows are the food masses in the lower small and the large intestine. Breakfast about 7 A. M. For some time before noon the food shadows showed no change (12 M). Shortly after 12 luncheon was taken. At 12.20 the food accumulated in the lower small intestine had been discharged into the ascending colon, which it distends. At 12.23 the distal end of this food mass was constricted off and later (12.25) passed along the transverse colon, where divisive movements take place (12.26); but at 12.31 the distal part of this mass is separated and rapidly passed through the descending colon (12.31 +) to the sigmoid flexure (12.31 ++)

(*sigmoid flexure*) between the descending colon and the rectum. It is chiefly in the ascending colon that the abstraction of water occurs. When, as the result of the discharge of new material from the small intestine into the large, the

ascending colon becomes distended, some of its contents are pushed into the transverse colon, and this material is rather rapidly passed by peristalsis through the descending colon, in the lower part of which it accumulates, being prevented from entering the rectum by the sigmoid flexure. Finally, with sufficient accumulation of this more solid material at the sigmoid flexure, stronger peristaltic contractions move the mass on into the rectum, which thereby becomes distended, and this gives the desire to empty the bowels. From this it will be seen why the bowels are more readily emptied after meals. It is also highly advisable to empty the bowels when this desire comes on, since otherwise the stimulus from distention loses its effectiveness and the continued abstraction of water hardens the feces.

34. Microbic life in the intestine. Occurring simultaneously with the chemical changes produced by the digestive juices are others produced by *microbes*,[1] which are always found in the intestine in large quantities. The acidity of the gastric juice keeps down the numbers of these germs in the stomach and, under healthful conditions, greatly limits their activity in that organ. We have seen, however, that some portions of the contents of the stomach are not acid in reaction during certain periods of digestion, and it not infrequently happens for this reason that unhealthful living and, especially, improper eating may result in serious gastric indigestion with excessive bacterial decomposition of the food. The production of gas, leading to flatulence and belching, is one of the most familiar results of such bacterial action.

[1] Microbes are exceedingly small forms of life, usually invisible to the naked eye, though visible under the microscope. They are often called "unicellular organisms" because they consist of a single cell; this cell is endowed with all the properties of life. They absorb and utilize food; they carry on chemical processes and excrete wastes; they grow and reproduce their kind. We subdivide microbes into *bacteria*, or plant microbes, and *protozoa*, or animal microbes. Those which live on materials contained in the bodies of other plants and animals are called parasites. (See Part II.)

In the intestine the less strongly acid (or even neutral or slightly alkaline) reaction is much more favorable to bacterial life and growth, and we accordingly find that the number of microbes is much greater in the small and large intestines. It is not the microbe itself, however, which is of importance to the organism as a whole, but the substances which it produces from the foods. Most of these substances are either harmless themselves or else are readily changed into harmless substances, either before or soon after entering the blood; others are poisons, but are normally present in such minute quantities as to be entirely negligible; more rarely they are produced in large quantities and may cause various ill effects either locally or upon the body as a whole.

The production of undue quantities of such harmful substances, most of which are derived from proteins, is chiefly dependent upon the food supply of the bacteria. This is normally kept low by the speedy and efficient removal of the peptones. Native[1] proteins are acted on rather slowly by bacteria and, in any case, must first be changed into peptones or simpler peptides before they can be further broken down into harmful bodies. If, however, the processes of absorption and excretion quickly and efficiently remove the digestive products, subsequent harmful decomposition of the food is prevented, for there are normally no bacteria in the blood. It is therefore of great importance to maintain the efficiency of absorption. This can be done in general only by leading a normal life — by taking sufficient muscular exercise, by proper habits of sleep and rest, by proper eating, and so on. The hygienic conduct of life tends to maintain all functions of the body in proper working condition, those of the digestive organs included; and nothing else can be

[1] A "native" protein is a protein as it occurs in nature before being changed by digestion or other chemical action. The proteins in food are largely native proteins, or else, what amounts to the same thing as far as the action of bacteria is concerned, native proteins coagulated by heat.

depended on, in the long run, to do this. To this subject we shall return in the chapters on hygiene, when dealing directly with the personal conduct of life.

FIG. 66. The intestinal structures concerned in absorption

In one villus is shown the close network of blood vessels immediately under the lining membrane; in the other villus, is shown the central lymphatic, or lacteal. Observe that the products of digestion must first be exposed to absorption by the blood vessels before they can enter the lacteal

The chief seat of the putrefactive decomposition of proteins is in the large intestine, where conditions are favorable for the activity of the special bacteria responsible for putrefaction. The reader will recall the provisions for completing the digestion of proteins and carbohydrates in the small intestine, and these certainly play a very important rôle in limiting harmful microbic action in the large intestine. However, it often happens, especially in middle life, that the quantity of food eaten, and of protein food in particular, must be considerably diminished to insure complete digestion of these nutrients in the small intestine and thus deprive the putrefactive bacteria in the large intestine of the material out of which to make deleterious substances.

We have thus far been dealing only with those microbes commonly found in the intestine. At times foreign microbes find entrance, some of which cause such diseases as typhoid fever, dysentery, or cholera. The action of these occasional intruders will be more fully dealt with in Part II.

III. The Passage of Digested Materials into the Blood: Absorption

35. Absorption is the name given to the passage of digested food materials from the cavity of the digestive canal into the blood. The word itself perhaps suggests that the products of digestion are received into the blood without change, as a sponge might absorb a mixture of peptides,

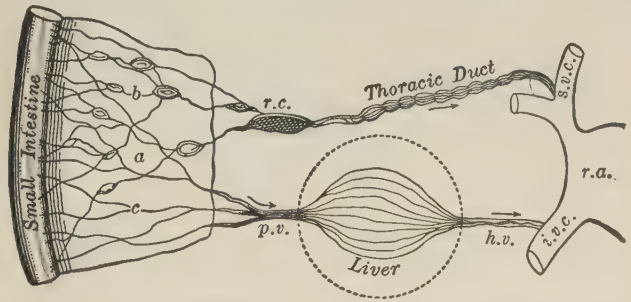


FIG. 67. The paths by which the products of digestion enter the general circulation

Those nutrients which are absorbed by the blood vessels (*c*) of the intestine pass by the portal vein (*p. v.*) to the liver before they can enter the right auricle (*r.a.*) through the hepatic vein (*h. v.*) and the inferior vena cava (*i. v. c.*). Those nutrients which are absorbed by the lacteals (*a*, *b*) pass directly to the superior vena cava (*s. v. c.*) through the receptaculum chyli (*r. c.*) and the thoracic duct

amino acids, sugar, fatty acids, soaps, and inorganic salts. Such, however, is by no means the case, and the actual physical and chemical processes of absorption are complicated — far too complicated to be discussed here. Suffice it to say that the alimentary tract is not lined by a dead membrane but by one composed of living cells — guardian cells which have the ability to pass one kind of material and to refuse another. Through such a barrier the products of digestion must enter the blood stream (see Fig. 66). In their passage through these cells some of the digestive

products are acted upon chemically so that they enter the blood in forms more available to the tissues of the body. Under normal conditions, absorption is effected almost exclusively in the small intestine, the stomach being unimportant in this respect and the large intestine being concerned chiefly with the absorption of water. It should be noted, further, that while the derivatives of the proteins and the carbohydrates are passed into the blood vessels of the villi, those of the fats pass instead into the central lacteal (see Fig. 66).

The object of the whole process of alimentation, digestion, and absorption would seem to be that of supplying, through the blood as a "middleman," nutriment to the cells of our muscles, glands, nerves, and other tissues, in the form which is best fitted for the use of each tissue.

IV. The Elimination of Unused Materials. Wastes

36. The elimination of intestinal waste. Those who are blessed with a good digestion sometimes find it hard to realize that the preparation of food for absorption through the delicate membranes lining the alimentary canal is a difficult and complex process, requiring much delicate physical and physiological apparatus and involving various and important chemical reactions. Even when they realize this, they rarely appreciate the indispensable coöperation and fine adjustment of the several parts and processes concerned. It is just here, however, that a clear understanding is important, for without this it is not easy to see how disorders of digestion arise.

Let us, then, remember that the efficient handling of the food in the stomach is aided by the preparatory crushing it receives in the process of mastication; that in the stomach an adequate and efficient secretion of gastric juice must take place, and that this begins as the result of nervous events connected with our enjoyment of the food when eaten; that

the continued secretion of gastric juice is secured, further, by stimulation of the mucous membrane of the stomach by the peptones which the psychic secretion has formed from the proteins of the food; and, finally, that the chemical action of the gastric juice is aided by the peculiar contractions of the muscular coat of the stomach. All these agencies *working together* deliver the food to the intestine in a finely divided state, well adapted, as indeed is absolutely necessary, to secure the proper contact of the food with the pancreatic juice, the bile, and the intestinal juice.

The flow of pancreatic juice, moreover, is partly the result of the action of the hydrochloric acid of the chyme on the walls of the intestine, while the efficiency of the action of the pancreatic enzymes depends upon the simultaneous action of the bile and the intestinal juice; lastly, the chemical action of these juices, as well as the final act of absorption, requires the coöperation of the muscular coat. Healthful conditions with respect to bacterial action similarly depend upon all else occurring as it should.

Keeping these facts in mind, it is easy to appreciate the possibility of diarrhea or constipation, the latter consisting in the retention of wastes, the poisonous constituents of which may be absorbed into the body and cause discomfort, headaches, and malaise. When all the digestive processes work together properly, there should be a perfectly natural and regular evacuation of the bowels. The frequency of such evacuation varies somewhat and is largely a matter of habit; with some people it is twice a day, with some once every other day, *but with the vast majority it is normally once every day and at about the same time.* Where this is not the case there is reason to believe that some part of the work of digestion is not being properly performed. The trouble is not ordinarily in the mechanism governing the actual discharge of the feces from the rectum, but in a derangement

somewhere else; it may be entirely the fault of the mechanism of peristalsis, or it may be due to imperfect secretion. In all cases it means that *something is wrong*, and the remedy should be sought, not in drugs or pills, but in *removal of the cause*. A moment's consideration will show the reasonableness of this position. If a watch loses time because it needs cleaning, we do not seek a remedy in drugs, but in its cleaning, better adjustment, and good care; and the remedy for diarrhea or constipation should in all cases be sought in the better conduct of life. Is enough muscular exercise being taken? Is the diet properly chosen? Are we drinking enough water? Especially, is the food of sufficient bulk, and does it contain enough laxative material (such as fruit)? Above all, are we getting enough sleep? Are we overworking, or do we work too long at a time without resting? Is our clothing not warm enough, or are we overclad? Such are the questions which should be seriously asked. The student of personal hygiene cannot lay to heart too seriously the truth that the man who goes from day to day, from week to week, from year to year, neglecting the warnings of diarrhea or constipation, only reaps the harvest of his folly when in later years he suffers loss of health and of bodily comfort; and it is nothing short of impiety to marvel under such circumstances at the "mysterious" ways of a Providence who so "afflicts" His creatures. It is no exaggeration to say that the regular discharge of the wastes is quite as important as the regular feeding of the body, and that no less pains should be taken to form good habits in the one case than in the other. Many of the headaches, many of the bad feelings, and many of the bad tempers of the world are due to neglect of this simple duty. No city, however well-fed or beautiful, the drains of which are choked with filth, can long remain either wholesome or attractive — and the human body is essentially a city teeming with living cells.

CHAPTER IX

THE CIRCULATION OF THE BLOOD

I. Blood and Lymph

1. The blood as a common carrier. In previous chapters some of the more general features of the circulation have already been touched upon. In studying the parts of the body the student has become somewhat acquainted with the heart, the arteries, and the veins; in considering the typical structure of the organs (Chapter III) he has seen how the arteries are connected with the veins by a system of communicating tubes, the capillaries, through the thin walls of which interchange takes place between the lymph and the blood; and in studying the interdependence and coöperation of the cells and organs (Chapter VI) he has learned how the blood leaving each organ returns to the heart, there to be mixed with that coming from all other organs and thence pumped first to the lungs and then to the rest of the body. The need of a circulation is obvious, for the food received from the alimentary canal and the oxygen received from the lungs must somehow be carried to the muscle fibers, the nerve cells, the gland cells; the cellular wastes must be taken away to the organs of excretion; and the internal secretions of the body must be transported from the organs in which they are made to those in which they are to be used. In other words, it is a necessary corollary to the fact that no cell or organ "liveth unto itself" that there should be some common carrier of matter and of energy from one organ to another. Such a common carrier is the blood. The

analogy of the blood system of the body with the railway system of a country is instructive. As different persons and different communities in any country make different products and have different needs, it becomes more and more necessary that the means of communication between them be extensive and efficient. Hence the remarkable growth of the railroads, or common carriers, of any country in which industrial development produces increasing division of labor.

The blood, which is thus the common carrier, first between the various organs and second between each organ and the outer environment, is the net product of the united work of all the organs: from the alimentary canal it receives water and the products of digestion; from the lungs it receives oxygen; each organ contributes its share of waste products or of internal secretion, while some influence the composition of the blood by removing from it certain ingredients.

2. The microscopic structure of the blood. Examined under the microscope the blood is seen to consist of a liquid portion, the *plasma*, crowded with small solid bodies, the *corpuscles*. These are of two kinds: the *red corpuscles* and the *white corpuscles*.

Important data on the number, size, and surface area of the corpuscles will be found in connection with Fig. 69.

3. The blood plasma and the lymph. The *blood plasma* is an exceedingly complex fluid consisting of 90 parts of water and 10 parts of solids. The approximate composition of the latter is as follows: 8 parts of protein; 1 part of mineral matter (compounds of sodium, potassium, calcium, and magnesium with chlorine, sulphur, and phosphorus); and 1 part of extractives, which include a great variety of substances produced during the physiological activities of the body and indicative of the chemical changes taking place in the organs.

The *lymph* is a clear fluid, closely resembling the blood plasma. The cells of the body generally are bathed with lymph, not with blood; in other words, the lymph and not the blood is the immediate environment of the cells. Lymph is sometimes described as blood minus its red corpuscles; but this statement, though convenient, is not strictly correct, since the amount of waste products in lymph is greater than in blood, while the amount of food material is less (see Chapter IV). As the blood is a product of the united chemical activity of all the organs of the body, so the lymph of each organ is derived from the cells of that organ and from the blood flowing through it. Lymph thus has a double origin and, of course, shows very considerable differences of composition in different organs.

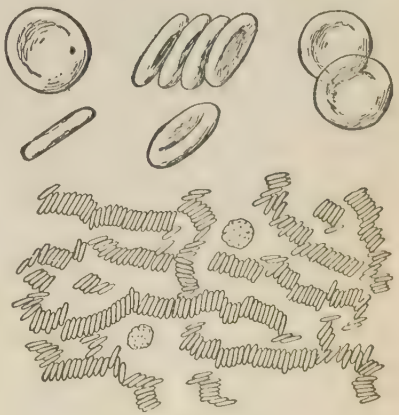


FIG. 68. Structure of a drop of blood as seen under the microscope

Above are shown nine red corpuscles highly magnified; below, less highly magnified, the appearance of the blood soon after being drawn. Two white corpuscles are shown, and the red corpuscles stick together, forming "rouleaux." Size of a red corpuscle, 7.7 μ wide, 2–4 μ thick. Diameter of a white corpuscle, 5–10 μ. Number of red corpuscles in the adult human body, 4,500,000–5,000,000 per cubic millimeter; number of white corpuscles, 4500–13,000 per cubic millimeter, according to the state of digestion and of general health. Surface area of all the red corpuscles of the blood, 3000 square meters (30,000 square feet, or approximately four times the size of a baseball diamond). (1 μ, or *micron*, equals 0.001 millimeter)

4. The red blood corpuscles. The red corpuscles (*erythrocytes*) are pigmented, biconcave disks with no nucleus; they are normally confined to the blood vessels and are carried around passively in the blood current without

active movements of their own (Fig. 69). The main function of these corpuscles is to carry oxygen from the lungs to the tissues, a function which will be further studied in connection with respiration. They contain a pigment, *hæmoglobin*, which gives to the blood its red color and carries the oxygen.

5. The white blood corpuscles. The white corpuscles really comprise several different kinds of cells, called collectively *leucocytes*. These may be subdivided into two main groups—nongranular cells (*lymphocytes*) and granular cells (*polynuclears*). These cells are not confined to the blood, but work their way out of the blood vessels between the cells of the capillary walls and are often found in the lymph spaces of the tissues as *wandering cells*. The latter term refers to their movement from place to place. The cytoplasm of the white corpuscle is a thick, viscous fluid without constant or definite form. In locomotion the cytoplasm flows slowly from some part of its surface in the direction of motion, forming what is known as a *pseudopodium* (from the Greek, meaning "a false foot"), as shown in Fig. 69; the rest of the body of the corpuscle then flows into the pseudopodium. By the continuation of this process the white corpuscles make their way through the spaces of the connective tissue. Locomotion by means of pseudopodia is frequently spoken of as *amœboid*, from the amœba, a unicellular animal which moves in the same manner. The

FIG. 69. Amœboid movement

Showing four consecutive positions of a white corpuscle in a group of red corpuscles, by means of a pseudopodium

white blood corpuscles contribute to the formation of new tissue in the healing of wounds, combat the invasion of the body by bacteria, and promote the removal of diseased tissue. Their functions will be explained more fully in the chapters dealing with focal infections and communicable diseases.

II. Mechanics of the Circulation of the Blood and of the Flow of Lymph

One of the greatest discoveries ever made in physiology was that of the circulation of the blood. As late as the settlement of the earliest English colonies in America it was thought that the blood moved back and forth in the blood vessels, as the waters in the sea ebb and flow; but of any *circulation*, in the sense of a steady stream returning to its source, there was no complete idea; and it was not until 1628 that William Harvey, an English physician, proved beyond the shadow of a doubt that the blood in the body of all the higher animals flows like a stream always in one direction, ultimately returning to its source.

Tests made upon various animals have shown that this circulation is accomplished in the surprisingly short time of from twenty to thirty seconds; which means that the whole mass of the blood (in man about twelve pints[1]) passes between three and four thousand times a day[2] through the various organs of the body, bringing to them their food, carrying away their wastes, and in general helping to maintain normal conditions. By what hydraulic machinery is this marvelous work done?

[1] Some physiologists estimate the total quantity of blood at as much as 7.5 per cent of the weight of the body; others, at as little as 5 per cent. An exact determination cannot be made. Employing the larger figure, a healthy person of 160 pounds would have approximately 12 pints of blood in his blood vessels.

[2] This estimate is based on an approximately equal distribution of hours among work, recreation, and sleep.

6. The motive power of the circulation as a whole; the beat of the heart. Whenever a mass of liquid is kept in motion we naturally look first for the motive power. In answering the question, What makes the blood circulate? we shall find that while there are several causes, one of these, namely the beat of the heart, is vastly more important than all the others combined. This fact is now so familiar that it is hard to realize that we owe to Harvey not only the discovery of the circulation but also the discovery of the meaning of the heart beat. Before his time, to be sure, the living heart had been seen at work, alternately shrinking in size and then swelling, the shrinking being called *systole* and the swelling *diastole*; but these changes in size were regarded as the results of the contraction and expansion of certain "vital spirits" which the arterial blood was then supposed to contain, and not as muscular contractions and relaxations. Harvey showed that *the heart is a powerful muscle* and that its systole is a muscular contraction; that during systole it becomes hard, just as the biceps muscle does when it shortens, and during diastole soft and flabby; he also proved that with each systole the heart drives or spouts blood into the large arteries (the aorta and the pulmonary artery), and that this blood is prevented from flowing back into the heart during diastole by membranous valves at the very beginning of the large arteries in question.

FIG. 70. The circulation of the blood as seen in the small arteries and capillaries of the web of a frog's foot

7. The heart a muscular force pump. The beat of the heart, even to its most minute detail, is one of the most important as well as one of the most interesting subjects in

physiology; everything in the body hangs on its proper efficiency and regularity, and it cannot be too thoroughly studied. For our present purposes it will suffice to describe the heart as composed essentially of a pair of muscular force pumps. Dissection shows that it is divided into right and left halves (see Fig. 71), completely separated from each other, and that each half consists of two chambers — an auricle and a ventricle. The auricles, into which the great veins open, have thin muscular walls and are comparatively small in size; the ventricles, on the other hand, from which the great arteries arise, have thick muscular walls, especially the left ventricle. The ventricles, indeed, constitute the principal part of the force pump; the auricles merely facilitate the work of the ventricles and for purposes of elementary study may be mostly neglected. The student should, if possible, examine for himself and actually handle the auricles, ventricles, and great blood vessels of a sheep's heart, which in size and structure sufficiently resembles the human heart. Fig. 17 and the plate facing page 17 should also be consulted.

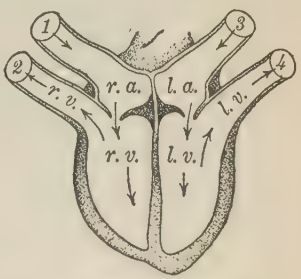


FIG. 71. Diagram showing the arrangement of the chambers of the heart and the direction of the blood flow

r. a. and *l. a.*, right and left auricles; *r. v.* and *l. v.*, the corresponding ventricles. *1*, the blood flow from the great veins; *2*, flow to the lungs; *3*, flow from the lungs; *4*, flow to the aorta and the arterial reservoir

8. The mechanics of the heart beat. All force pumps (Fig. 72) consist of two indispensable parts — some device for pressing upon a liquid within a chamber, and valves at the openings of the chamber so arranged as to allow the passage of the liquid in one direction only. Each ventricle of the heart is really such a pump and is provided with two

sets of valves — one set at the inlet, between the auricles and the ventricles, and the other at the arterial outlet. These valves permit blood to pass only from the great veins through the auricles and on through the ventricles to the great arteries. The contraction of the muscular wall of the ventricles produces pressure on the blood within their cavities; this pressure quickly and easily closes the auriculo-ventricular valves and simultaneously forces open the shut valves at the openings of the great arteries. In this way the right ventricle drives venous blood into the pulmonary artery, and the left ventricle arterial blood into the aorta. With the relaxation of the ventricles (diastole) pressure falls within their cavities, and were it not for the valves at the mouths of the aorta and the pulmonary artery, blood would regurgitate, or flow back, into the heart; but the valves prevent this "slip" (as it is called in hydraulics), and the ventricles again fill through the only open channel, that is, the one leading from the great veins and the auricles. Thus, by contractions rhythmically repeated, the heart continues to spout or deliver blood from the two sets of great veins into the two sets of great arteries. It is plainly a double force pump, or, better, a pair of force pumps lying and working side by side (Figs. 72 and 73).

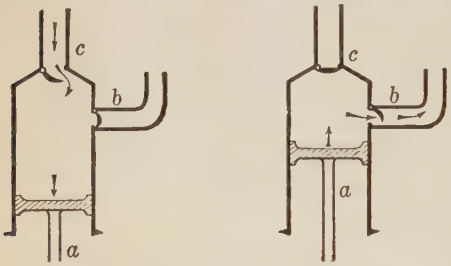


FIG. 72. Diagram of a force pump

When the piston (*a*) is drawn down, the valve (*b*) closes and the valve (*c*) opens, allowing the chamber to fill through *c*; but when the piston is pushed upward, *c* closes and the fluid is forced out through *b*

9. The arterial and the venous systems. To understand the exact nature and result of the work of the heart we must

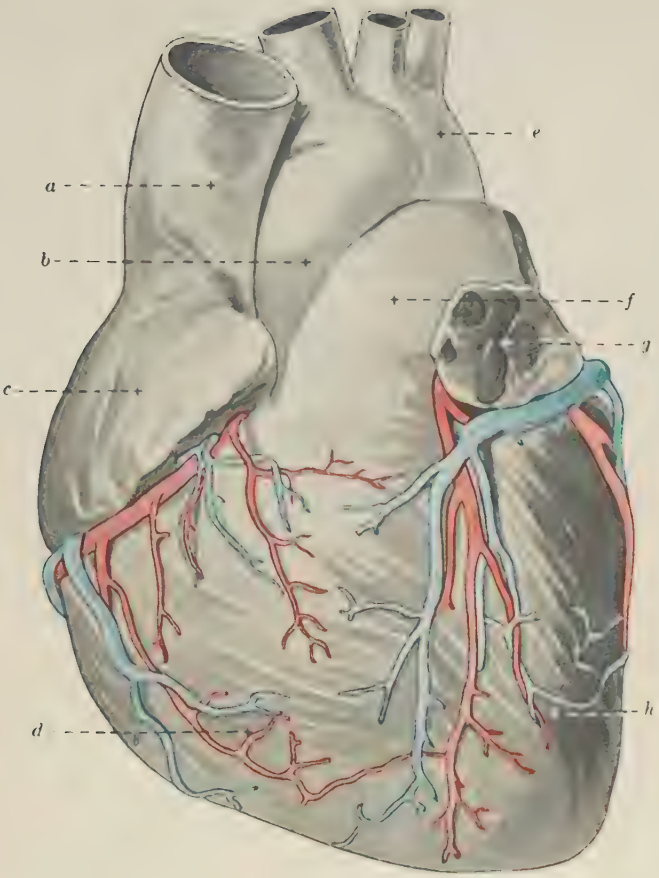


PLATE C. Ventral aspect of the heart. After Spalteholz

a, superior vena cava; *b*, beginning of aorta; *c*, right auricle; *d*, right ventricle; *e*, arch of aorta; *f*, pulmonary artery; *g*, left auricle; *h*, left ventricle. Some of the chief arteries (red) and veins (blue) of the heart are shown. The entrance of the pulmonary veins into the left auricle and that of the inferior vena cava into the right auricle are on the dorsal side of the heart and hence are not shown in the figure

now consider the relation of this living pump to the pipe system (arteries, capillaries, and veins) with which it is connected. The student should first trace the general course of the circulation in the simple diagrammatic representation given in Fig. 74. This shows that the blood which enters the aorta from the left ventricle must return to the right side of the heart and pass through the lungs before it can again reach the aorta. As the physical principles of the circulation are the same for the systemic and the pulmonary vessels, we shall confine our attention to the former.

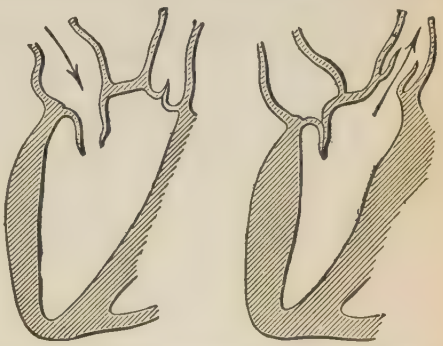


FIG. 73. The force-pump action of a ventricle of the heart

On the left is shown the condition during diastole; on the right, during systole

In the first place, we may observe that the heart pumps the blood into what is practically a large reservoir (the larger arteries) and that the blood flows from this reservoir to a second reservoir (the larger veins) *by various routes*, for the vessels of the different organs represent many alternative courses which the blood may take in flowing from the arterial to the venous reservoir. The blood stream, indeed, may be compared with a city water and sewerage system. The large arteries from the main source of pressure (the heart) correspond to the aqueduct leading from the reservoir to the boundaries of the city, the smaller arteries to the pipes extending from the aqueduct along the various streets, and the arterial capillaries to the water pipes within the houses; while the venous capillaries correspond to the house drains, the smaller veins to the street sewers, and

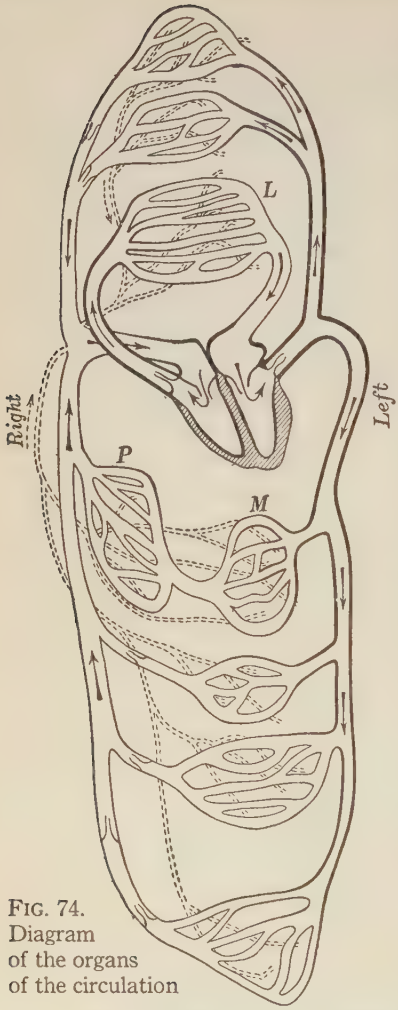


FIG. 74.
Diagram
of the organs
of the circulation

L, pulmonary circulation; *M*, circulation through the organs suspended by the mesentery, the blood being carried to the liver, *P*, before it returns to the heart. The circulation through other organs is indicated. Lymphatics are represented by dotted lines

the great veins to the main sewers. The water flows from the water pipes to the sewage pipes through the laundry, toilet, and kitchen fixtures. So in the vascular system a part of the blood pumped into the arterial reservoir, or aorta, finds its way into the venous reservoir by way of the skin, another part by way of the digestive organs, another by way of the brain, still another by way of the kidneys, and so on; but the flow in every case is essentially the same, namely, from a reservoir of high pressure to one of lower pressure.

10. The driving force for the flow of blood from the aorta; pressure in arteries and veins. The hydraulic conditions in the aorta may be illustrated by means of the following simple piece of apparatus: To an ordinary rubber syringe attach a piece of elastic rubber tubing, the other end of which

is closed by a detachable nozzle. If now the nozzle be removed and water pumped into the tube, it will be found that the flow from the open end consists of squirts or spouts and continues only during the stroke of the pump; if, however, we attach the nozzle and again pump water into the tube, the resistance caused by the small orifice of the nozzle prevents the water from flowing out of the tube as fast as the syringe pumps it in. *The tubing becomes distended with water.* Since, however, the tube is elastic,[1] and so tends to return to its original size, it continues to force the liquid out through the nozzle even between the strokes of the pump. The immediate cause of the steady flow from the nozzle is therefore the squeeze of the elastic rubber tube. The intermittent stroke of the pump produces distention of the tube, and the elasticity of the distended tube constantly forces the water out of the nozzle.

Closely similar conditions obtain in the arterial reservoir. Here the outlet is also through very small tubes, the *arterioles*, whose bore is not greater than $\frac{1}{50}$ or $\frac{1}{100}$ of an inch; this fact introduces the same condition as does the nozzle of our apparatus, that is, a *resistance* to the outward flow of the blood. Consequently the blood cannot flow out of the aorta as rapidly as it is driven in, and the extensible and elastic walls are necessarily stretched. The immediate effect of the heart beat is to keep the arterial reservoir overfilled, or distended, so that the *elastic reaction* of its walls is brought into play; and it is this elastic reaction of the arterial walls which is the immediate cause of the steady outflow through the small arteries and capillaries.

[1] An elastic body is one *which returns to its original shape* when it has been stretched, compressed, or otherwise deformed. Elasticity must not be confounded with "extensibility," or the property of allowing stretching. Thus when we "pull" taffy we deal with a body which is very extensible but which is practically inelastic. A body, indeed, may be extensible only with difficulty, but possess a very high degree of elasticity; ivory is a good example of this kind.

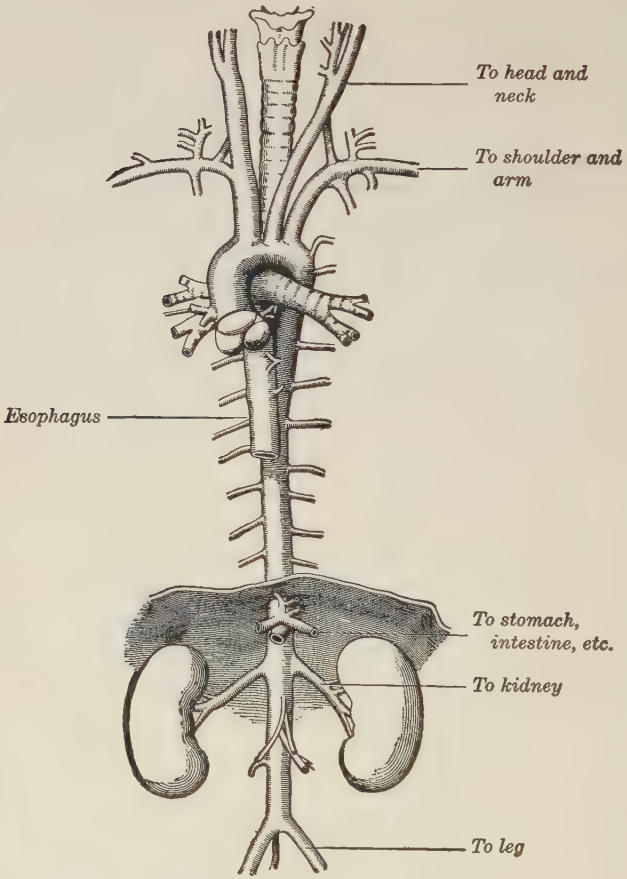


FIG. 75. The aorta and its main branches

At the beginning are shown the three pocket valves which prevent regurgitation of blood during diastole

The force of compression, or *pressure*, exerted by the elastic arterial walls is primarily exerted upon the blood within them; and the more the arteries are distended the greater will be the pressure exerted on the blood. A liquid thus

under pressure tends to find an outlet; should any part of the arterial walls be weak, as sometimes happens in diseased conditions, it is bulged outward; and, for the same reason, a flow of blood will take place through such outlets as are presented by the smaller arteries and capillaries. Moreover, the greater the pressure of the blood in the arteries, the more rapid will be the flow into the capillaries. Hence it is customary to use the *arterial blood pressure* as a measure of the force of elasticity exerted by the distended arterial walls.

The veins, on the other hand, are less elastic than the arteries; they are, indeed, more like mere conducting tubes through which the blood can flow back to the heart. They are not distended as are the arteries (since, for one reason, there is no resistance to the flow of blood out of them into the heart) and hence *venous blood pressure* is low.

Thus we have the conditions favorable for the flow from the aorta to the great veins — a *high* pressure in the arterial reservoir and a *low* pressure in the venous reservoir. It is the function of the heart, by continually pumping the blood from the veins into the arteries, to keep the arterial reservoir distended, thus maintaining *a difference of pressure in the two reservoirs. It is this difference of pressure which drives the blood through the organs.*

11. The distribution of the blood among the organs. Some organs require more blood than others, and the same organ often requires more blood at one time than at another. Thus muscles and glands, the seat of very active chemical changes, require more blood than a tendon; and a gland requires more blood during the process of secretion than during rest. How is the supply of blood to the organs regulated to meet their varying needs? In the first place, some organs are more vascular than others; those requiring a larger supply of blood receive a greater number of arteries from the arterial reservoir and have a closer network of

capillaries. But in addition to this, these smaller arteries contain circular muscle fibers (Fig. 76) whose contraction diminishes the bore of the tube. When an organ needs more blood the muscle fibers of its small arteries relax, thus permitting the arterial tubes to widen or dilate — just as when we want the water to flow faster into a washbowl, we widen the outlet from the pipe by turning the spigot a little farther. This increased flow of blood into the capillaries causes them to dilate (passively), so that the whole capillary network pervading the organ becomes distended. There is evidence, also, that the capillaries may at times actively change their caliber. When less blood is needed, the small arteries are caused to contract, just as a spigot may be partly turned off (p. 193), and this is followed by a decrease in the distention of the capillaries. In these ways the flow of blood to any organ is regulated to meet the varying needs of the organ in question.[1]

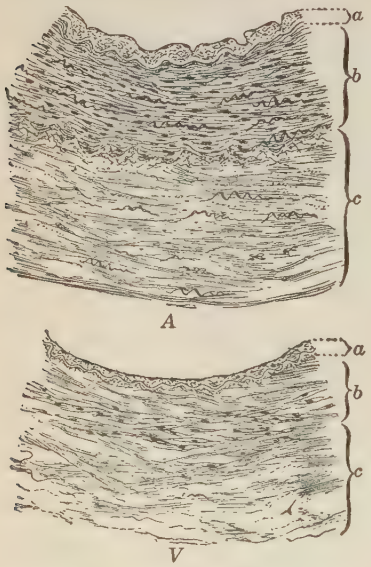


FIG. 76. Cross sections of portions of the wall of a smaller artery (*A*) and a smaller vein (*V*)

a, internal coat; *b*, middle coat, with muscle fibers; *c*, outer coat of connective tissue. The contraction of the circularly disposed muscle fibers narrows the bore of the tube

[1] In order that the student may become more familiar with these fundamental hydraulic principles of the circulation, such questions as the following should be answered: (1) What are the two principal factors whose variations change the amount of arterial pressure? Illustrate by an example or model. (2) How would the dilation of all the arteries of the intestine affect the general arterial pressure? (3) What would be the effect upon the amount of blood flowing through the skin under this condition?

12. Secondary aids to the circulation. In the preceding discussion we have seen that the cause of the flow of blood through the organs is the difference of pressure in the two reservoirs. We have further seen that this difference of pressure is maintained by the heart beat in pumping blood from the venous into the arterial reservoir. A moment's consideration will show that anything which hastens the flow of blood from the veins into the heart and so lowers pressure within the veins would similarly aid the circulation, since, with the same arterial pressure, more blood will flow into an empty vein than into one which is partially filled.[1] There are two factors which tend to empty the veins and in this way to aid the circulation. These are movements of the thorax in respiration and movements of the muscles and joints.

1. *The breathing movements.* The expansion and contraction of the thoracic cavity exerts a suction action on the large veins which lie therein. The exact mechanism by which this is accomplished must be left for consideration in the chapter on respiration. Suffice it to say here that just as the enlargement of the thorax, when we take in a breath, sucks air into the lungs, so it also sucks blood from the large veins outside the thorax into those which lie within it; because of the thickness of the walls of the arteries the same effect occurs to only a very slight extent in the arterial reservoir. During expiration, on the other hand, the reduction in size of the thorax forces air out of the lungs, and we might expect that it would similarly force blood from the veins within the thorax into those without. And this it certainly would do if the veins were not provided with valves which allow the blood to flow only toward the heart (Fig. 77). In

[1] The student should learn to appreciate what is meant by *filled, partially filled,* and *empty,* as applied to blood vessels. A filled vein is one which is distended, owing to the outward pressure of the blood it contains; an empty vein is one which is collapsed, owing to lack of blood enough to press outward; and a partially filled vein is, of course, intermediate.

general, therefore, both inspiration and expiration aid the circulation, the former by sucking blood into the thoracic veins and so emptying those outside, the latter by making this blood in the intrathoracic veins flow on more rapidly to the heart, whence it is pumped into the arteries. In a word, deep breathing greatly promotes good circulation.

2. *Movements of the muscles and joints.* The other secondary factor aiding circulation is the intermittent compression of the veins, or the so-called "pumping" action on the veins. This is brought about in two ways: (1) by the alternate contraction and relaxation of the muscles and (2) by the flexion and extension of the joints.

FIG. 77. The pocket valves in the veins

On the right is shown the external appearance of the vein at the valves when the latter are closed; on the left, a vein slit lengthwise and opened; in the middle, a longitudinal section of a vein

a. Whenever a muscle contracts it thickens and hardens; the veins and capillaries which are between the fibers and fiber bundles, or in the connective tissue between two contracting muscles, will thus have the blood squeezed out of them into the large veins; when the muscle relaxes, the empty veins and capillaries will readily fill from the arteries, since the valves of the veins will prevent any backward flow of the blood from the larger veins. Alternate contractions and relaxations of muscles therefore aid the flow of blood through this pumping action on the veins.[1]

[1] *Massage.* The action of massage is only another illustration of the same principle. By rubbing the legs and arms in the direction of the heart, the blood contained in their veins is forced onward and the circulation aided, both in the part rubbed and in the body as a whole, precisely as the circulation is aided when a muscle contracts.

b. A similar pumping action on the veins is exerted by alternate flexions (bendings) and extensions at any joint. In general, flexions force the blood out of the veins, while extensions allow them to fill; for example, the venous blood in the region of the knee is forced upward by flexion of that joint, and a new supply from below is sucked in on extension.

These aids to the return of the blood to the heart have a great effect on the circulation of the whole body; but they are of fundamental importance in promoting the flow of blood from the lower extremities, for this return is opposed by the downward pressure (weight) of the column of blood filling their veins. Without this aid, the blood would tend to accumulate particularly in the foot and the lower leg, and their veins would become distended (varicose); and, in consequence, the supply of nutrition and the removal of wastes would be retarded. This explains why it is more fatiguing to stand perfectly still than to walk, and why clerks in stores are likely to complain of their shoes becoming too tight and may develop varicose veins.

When we reflect (1) that most of our muscular activities consist of alternate contractions and relaxations of muscles and alternate flexions and extensions of joints and (2) that muscular activity increases the respiratory movements, we can at once appreciate how greatly muscular activity aids the circulation and how important it is to the maintenance of health. But aid given to the circulation is not the only contribution made to the welfare of the body by muscular activity; it also favorably affects the muscles themselves, builds up the strength of the heart, trains the temperature-regulating mechanism (p. 372), increases the capacity of the lungs, promotes digestion and the elimination of wastes, and stabilizes the nervous apparatus. Thus muscular activity is essential to the well-being of the whole body; one who neglects physical exercise cannot develop into a vigor-

ous adult nor maintain that state of healthy efficiency necessary for service and happiness.

13. The lymphatics. Important as are the sucking action of the breathing movements and the pumping action of contracting muscles as aids to the circulation of the blood, they are even more important as causes of the flow of lymph along the greater lymphatic trunks toward the heart. Reference to the general origin of lymphatics, as described in Chapter III, will show that the lymph in the lymph spaces, unlike the blood in the capillaries, has not behind it a high-pressure reservoir; there is no such *force from behind* to send it onward, since the lymphatics arise blindly in the tissues. What, then, makes the lymph flow along the lymphatics toward the heart?

The lymphatics resemble the veins in structure, having thin walls and pocket valves; like the veins, most of them originate in extrathoracic organs and join or combine to form larger trunks as they proceed toward the thorax. All of them finally unite in two large lymphatics within the thoracic cavity, and these open into the great veins near the heart. (Figs. 32 and 74 should be consulted in this connection.) It is at once clear that the breathing movements must exert on the lymph within these thin-walled vessels exactly the same suction action as they exert on the blood in the veins, and anything which increases this suction action, such as the deepened breathing movements during muscular activity, must necessarily increase the flow of lymph from every organ of the body. On the other hand, a pumping action on the lymph in the organs results from all rhythmic movements of parts of the body with reference to one another, since each change of position carries with it some change of external pressure on lymphatics. Familiar examples are the movements of arms and legs in locomotion, and of the diaphragm and lungs in respiration.

It has also been supposed that a third cause of the lymph flow is the passage of waves of constriction (peristalsis, compare page 147) over the larger lymphatics. This, however, probably plays only a minor part.

Finally, in the formation of lymph from the blood, more water generally passes from the capillaries to the lymph spaces than from the lymph spaces into the capillaries. Under these circumstances, at least at certain times, the lymph spaces become distended and a moderate pressure obtains in them. This we may speak of as the *active force of lymph formation*, and it constitutes a fourth factor in causing the lymph flow.

We have already pointed out the importance of the lymph flow in maintaining the lymph currents about the living cells; we are now able to appreciate the importance of those agents which secure this flow. As enumerated above, they are four in number: (1) suction action of the breathing movements; (2) pumping action of muscular movements or massage; (3) active force of lymph formation; (4) peristaltic contractions of the large lymphatics.

Of these the fourth is at least doubtful and in no case of great importance; the other three may therefore be regarded as the chief causes of the lymph flow, and of these the first and second are brought into most effective action by muscular activity; this deepens the breathing movements and so increases their suction action on the lymph, while the movements of the body exert on the lymphatics a pumping action which is largely lacking during complete inactivity. The great practical importance of this aspect of the subject will be discussed later in those chapters which deal with the hygiene of muscular activity (Part II).

III. The Adjustment of the Circulation to the Needs of Everyday Life

The total quantity of blood in the body (ten to fourteen pints) is not enough to furnish a working supply to all organs at the same time; and since, in general, whenever an organ is in a state of activity it receives more blood, and when it is at rest it receives less, our daily life with its changes of activity among the organs makes necessary frequent adjustments of the circulation to the needs of the organs at various times.

Some of these adjustments are matters of familiar experience. The increased flow of blood to the skin on a warm day makes the veins stand out and the face red, and we are conscious of the more rapid heart beat during muscular activity, even in an act so simple as running upstairs. Other adjustments are not so evident, but betray themselves by their results, as happens after a hearty meal when the demand of the digestive organs for blood lessens the supply to the brain and we feel disinclined to hard mental work. We may begin our study of these adjustments by learning what occurs in the circulation during some of the more common activities and events of daily life.

14. The circulation during exposure to heat and cold. Heating a part of the body produces in its circulation an effect the opposite to cooling. Accordingly, very important physiological and hygienic results may be obtained by the application of heat and cold.

1. *Cold.* When the skin is cooled, its blood supply is diminished; the veins no longer stand out prominently; if a small area be made pale by pressure (thus driving the blood out of its capillaries), the pallor passes off very tardily on releasing the pressure. This experiment shows that blood is flowing into the skin very slowly.

2. *Warmth.* Conversely, the application of heat causes the veins to stand out prominently; the red color instantly returns on removal of pressure. These observations show that the supply of blood is abundant and that it is flowing rapidly from the arterial reservoir to the skin.

These variations in the supply to the skin (and the same holds for other organs) are due (see page 172) to changes in the diameter of the arteries and capillaries of the skin, and they serve to regulate the flow of blood as the accelerator on an automobile regulates the flow of gasoline.

The changes in the blood flow through the skin are accompanied by corresponding but inverse changes in the internal organs. On a cold day the stomach and intestines, the pancreas, the liver, the kidneys, and other vital organs are richly supplied with blood, while on a warm day their blood supply is diminished. In the former case the blood withheld from the skin finds its way into the internal organs; in the latter case the skin draws upon these organs for its needed supply. The circulation in the internal organs *compensates* for that in the skin.

It should also be noted that an increase in the activity of an organ is accompanied, or rather preceded, by an increase in its blood flow, obviously for the purpose of supplying the necessary increase in energy and removing the increase in waste products. In general, also, an increase in the blood flow is followed by an increase in activity, and a decrease in blood flow by a decrease in activity. Warming the organ increases the blood flow, while cooling effects the reverse; and the change in the blood flow of one organ is followed by a compensatory change in other organs (p. 180). In these phenomena lie the explanation of the effects that follow contact of parts of the body with hot and cold objects; for example, iced drinks, hot and cold baths, overheated dwellings, and different climates, latitudes, and seasons.

15. The reason for compensatory changes. We have seen that it is the function of the heart to keep the arterial reservoir adequately distended with blood, thus supplying a steady driving force for the flow of blood through the organs. When the small arteries (*arterioles*) of the skin widen on a warm day, blood escapes more rapidly into the skin from the arterial reservoir. This alone would diminish the amount of blood in the reservoir unless the heart pumped more blood or unless the dilation (increased bore) of the cutaneous arterioles were *compensated* by a constriction elsewhere, so that the total drain on the reservoir remained the same. In the case in question it is the latter of these alternatives which is adopted, and the reservoir is kept filled without calling on the heart to pump more blood.

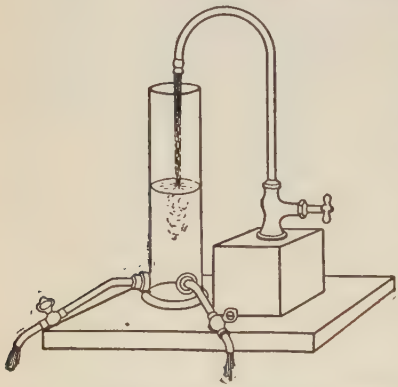


FIG. 78. Simple apparatus to illustrate the relation between the output of the heart, the peripheral resistance, and the general arterial pressure

The amount delivered by the faucet represents the output of the heart, and is one factor in keeping up arterial pressure; two alternative routes of outflow, each capable of regulation, represent the arterioles to different organs. Compensatory constrictions and dilations and other hydraulic conditions described in the text may readily be imitated

Conversely, on a cold day the diminution of the outflow into the skin would lead to a backing up or accumulation of blood in the great arteries, and so to their increased and perhaps undesirable distention, if the dilation of the arterioles of internal organs did not provide an outlet for the surplus blood.

Nowhere, perhaps, is this principle of compensatory dilation or constriction of arteries in one region, to allow for the

effect of the opposite change in some other region, so highly developed or so fully applied as in the reactions of the body to changes in external temperature.

16. The circulation during muscular activity. During muscular activity the arterioles of the muscles and of the skin are dilated, the former in order to supply more blood to the working organ, the latter to aid in the discharge of the excess of heat produced by the contracting muscles. The heavy drain upon the arterial reservoir by these two large areas (among the largest in the body) is compensated to some extent by the constriction of the arteries of the digestive and other internal organs. This alone, however, would not suffice to keep the arterial reservoir filled; and we accordingly find that the heart beats more rapidly and more powerfully, pumping more blood into the aorta in a given time.

It is very important to remember that muscular activity is the one condition of life which materially increases the work of the heart; at other times the greater demand for blood for a working organ is met more or less successfully by withdrawing blood from a resting organ, while the supply to the whole arterial system, and hence the work of the heart, remains approximately unchanged. During muscular exercise, and then only, is the heart called upon for decidedly increased work; and, as with skeletal muscles, its strength (its ability to meet strain and emergencies and to withstand fatigue) depends to a great extent upon the training given it in this way.

Muscular activity also influences the circulation indirectly by increasing the action of its secondary driving forces — the suction action of the respiratory movements and the pumping action of the contracting muscles on the veins. These are among the most important effects of this agent upon the flow of blood, but they are too complicated for detailed discussion here.

It is sometimes stated that muscular exercise quickens the circulation. This is true in the sense that the heart pumps more blood into the pulmonary artery and the aorta than during rest. From this it follows that during exercise more blood flows through the lungs, and that blood flows more rapidly out of the arterial reservoir, but it does not mean that blood flows more rapidly through all organs at the same time, for the digestive and other internal organs at such times actually receive blood more slowly. Indeed, we may say that the quickening of the circulation during exercise is chiefly confined to four important organs — the muscles, the skin, the lungs, and the heart; in other organs the change is relatively slight, as, for example, in the brain; while in still others, notably those of the digestive system and the kidneys, the speed is diminished.

17. The circulation during sleep. An adequate blood supply is necessary to the full activity of the brain; when the circulation in this organ is seriously interfered with, imperfect mental action or even unconsciousness is a result. Thus when all the arterioles of the body dilate, or the heart beat is slowed down in consequence of some sudden shock, so that pressure in the arterial reservoir falls too far, the driving force for the flow of blood through the brain as well as through other organs is diminished, and the person may lose consciousness, or faint. Most cases of fainting are traceable to one or the other of these causes (Fig. 79).

The most familiar and most common example of unconsciousness, however, is that of sleep, which in so many respects resembles fainting as to suggest that the unconsciousness in both cases is due to the same cause, namely, a lessened blood supply to the brain. Unquestionably the amount of blood flowing through the brain is greatly lessened during sleep. The evidence for this statement cannot be given here in full, but it is known that where acci-

dent has destroyed a part of the rigid bone of the skull, and the wound has been covered over by connective tissue and skin, the scar sinks in during sleep — indicating less blood in the brain — and returns to the level of the general surface of the head when the subject awakens.

Upon this point of diminished blood supply to the brain during sleep almost all physiologists are agreed; there is also general agreement that the arm and the leg increase in volume when we go to sleep, and this is thought to be due to a dilation of the arterioles of the skin. It is very significant, on the other hand, that the arm shrinks in volume when the brain is active in mental work, and especially in mental work involving the active interest or mental concentration of the person experimented on.

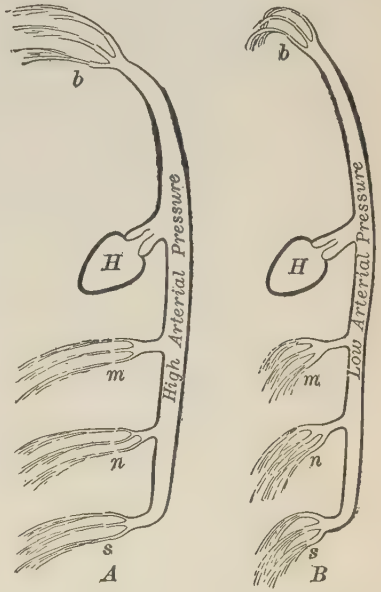


FIG. 79. Showing the relation between general arterial tone and the supply of blood to the brain

In *A* the arterioles of the organs *m*, *n*, *s* are constricted, raising general arterial pressure, which forces a large amount of blood through the brain, *b*. In *B* the arterioles of *m*, *n*, and *s* are dilated, general arterial pressure is low, and less blood is forced through the brain. *H*, heart

It is thought by some that other vascular areas — that of the abdominal cavity, for example — behave in this respect in the same way as the skin, but on this point the evidence is not conclusive. It is, indeed, not improbable that these other vascular areas play some part in the regulation of the flow of

blood to the brain during sleep; but it is not likely that they stand in the same intimate relation to it as does the skin.

The fact is clear, however, that a close relation exists between cutaneous circulation and the maintenance of proper vascular conditions in the brain. Mental work, for example, is more difficult for most people in very warm weather, because at that time the cutaneous arterioles are widely dilated; and, on the other hand, it is easy to understand why the constriction of the vessels of the skin by cold makes it difficult to go to sleep without sufficient bedclothes.

18. The circulation during the digestion of a meal. After eating a meal more blood is needed in the secreting digestive glands (especially the stomach and pancreas) and also in the intestinal organs of absorption, the villi. This need is greatest during the first hour or two, when there is the largest amount of food to be worked upon. We find, accordingly, that the arteries of these organs then dilate to such an extent that the mucous membrane of the stomach and intestine, which is pale pink while those organs are at rest, now becomes very red on account of the large amount of blood flowing through them.

There is probably some compensation for this in other organs, but it is an imperfect compensation. The drowsiness which is apt to come on after a hearty meal is probably an indication that these compensations are not complete and that, owing to the fall of arterial pressure, the brain is not receiving its normal blood supply.

19. Some practical applications. We may pause here to consider some important practical applications of these facts. While the most active secretion is in progress nothing should be done which will take blood away in large quantities from the stomach. Muscular exercise, for example, then as always, dilates the arterioles of the muscles and skin and *constricts those of the digestive organs*; this is obviously an unfavorable

vascular condition for the act of secretion. If the meal be a light one, so that comparatively little of the digestive juices is required, no harm may be done by taking exercise after a meal; but where the meal is heavier it is almost always unwise, especially in warm weather. Similar considerations, which are likewise in full accord with experience, indicate that it is unwise to eat as large meals in very warm weather as in cooler weather. The larger the meal, the greater the amount of gastric juice required to start its digestion; but in warm weather the arteries of the stomach and intestine tend to be constricted (p. 179), so that it is difficult to secure an adequate blood flow through these organs, and their efficiency is to this extent impaired.

It is sometimes stated that mental work immediately after meals causes indigestion by taking blood away from the digestive organs and sending it to the brain. It is very doubtful, however, whether the increased blood flow to the brain is secured largely at the expense of that to the digestive organs. While instances might be cited of indigestion among people who do mental work upon a "full stomach," it must be remembered that these are usually people who fail to take proper exercise or sufficient sleep and rest; the indigestion from which they too frequently suffer is more often attributable to these causes, or to a habit of worrying, than to the fact that the digestive organs are deprived of their proper blood supply.

20. The mechanism of the regulation of the flow of blood. Having thus considered exactly what takes place in the circulation during some of the more important events of daily life, we may next inquire briefly into the physiological mechanism by which these adjustments are secured. Its most important features are (1) the regulation of the pumping action of the heart, or output into the arterial reservoir, and (2) the regulation of the outflow from the arterial reservoir

through the arterioles and capillaries of the organs. These two must be adjusted to each other in order that the reservoir may remain full and thus the driving force for the flow through the organs be maintained, so that increased activity may be provided for by an increase in fuel for power. We shall go into the details of this very beautiful but complicated mechanism only far enough to enable the student to appreciate certain principles of fundamental importance in the practical conduct of life.

21. The regulation of the pumping action, or output, of the heart. The beat of the heart is primarily due to events which take place within the heart itself. We have seen that this beat is a muscular contraction. But the cardiac muscle differs from the skeletal muscles in that it does not require an impulse from the central nervous system to throw it into activity. When the heart is cut off from connection with the rest of the body, it continues to beat for a time and, if supplied with warm blood, it may be kept beating for hours. Thus the heart beat is *automatic*, the heart containing within itself a complete mechanism for doing its own work.

The output of blood from the heart varies considerably from time to time. At times it may be as low as three quarts a minute and at other times as high as twenty-three, the quantity being largely determined by the drain made at the time upon the arterial reservoir, for the amount of blood pumped into the aorta must at all times be nicely adapted to the requirements of the organs for nutrition. It will be seen at once that this involves a wide range of adjustment both in the rate of the heart beat and in the output per beat. The way in which these two factors coöperate to influence the amount of blood pumped per minute will be readily understood on referring to the diagram of the force pump (Fig. 72). The effects of changes in rate of beat and output per beat are shown in the following table:

Rate per Minute	Output per Beat	Output per Minute	End Result
70 beats	100 cc.	7000 cc.	Normal
90 beats	100 cc.	9000 cc.	Increase
70 beats	130 cc.	9100 cc.	Increase
80 beats	112 cc.	8960 cc.	Increase

From these calculations, it will be seen that the output per minute (and this is what counts) may be increased by increasing (1) the rate of the heart beat, (2) the output per beat, or (3) both simultaneously.

22. The regulation of the rate of the heart. Quickening of the heart rate, or pulse, is one of the means of increasing the movement of the blood; slowing produces the opposite effect. There are two mechanisms for changing the rate of the heart, the stimuli conveyed by (1) the cardiac nerves and (2) the blood stream.

1. *The cardiac nerves; the augmentor and inhibitory nerves of the heart.* We have noted above that the heart beat is automatic. Nevertheless it receives from the central nervous system two pairs of nerves which are able to influence the rate and force of its automatic beats: (1) the augmentor and (2) the inhibitory.

a. The *augmentor*, or *accelerator*, nerves carry to the heart from the central nervous system (spinal cord division) impulses which stimulate that organ to beat more rapidly or more forcefully, or both. In their action we have an example of the same sort of nervous activity which stimulates the muscle fibers to contract, the gland cells to secrete, and the nerve cells to execute reflexes. The only difference is that here it is not a quiescent organ which is excited to action but an acting organ which is excited to greater activity. The impulses sent through these nerves may be the result of changes in the brain (as from excitement, fear, anger, or even thought of beginning a task) or in the

sensory nerve endings variously distributed throughout the body (a reflex effect of pain, of motion of the joints, of digestion, and even of sight, taste, and smell). Thus the heart is speeded up when we are angry, when we suffer pain, when we see a pedestrian hit by an automobile, when we use our muscles or even think about using them, and in countless other circumstances.

b. The *inhibitory* nerves carry from the central nervous system impulses which slow the heart or lessen its force, or both. They act, as it were, like a brake on a wheel, checking the activity of the automatic beat. In the inhibitory nerves we have an example of an effect just the opposite to that usually following a nerve impulse. Here, instead of setting the organ to work or stimulating it to increased activity, the activity is diminished and in extreme cases may be checked or stopped altogether. In our subsequent studies we shall meet with many examples of this effect; inhibition is as characteristic and important a feature of the nervous system as excitation (p. 331). The inhibitory mechanism of the heart is normally called upon when the distention of the aorta becomes excessive, that is, when the blood pressure rises higher than is necessary to meet the needs of the body.

2. *Stimuli conveyed by the blood stream; temperature effects and chemical actions.* The blood in its passage through the body is changed as regards its temperature and its composition. These changes produce alterations in the rate of the heart as follows:

a. Heat increases the heart rate, and *cold* has the opposite effect. Both of these changes are necessary in the regulation of the body temperature; the hot blood being driven in greater volume, for instance, through the skin and the lungs, would be cooled more rapidly; if, in the process of being cooled, it became too cold, then the heart would be slowed and the loss of heat decreased.

b. The chemical actions with which we are concerned in this case are those of *carbon dioxide, lactic acid,* and *adrenaline.* The first two have been referred to in various connections as products of muscular activity. When they reach a certain concentration in the blood stream, they accelerate the heart. Thus the flow of blood to the active organs is increased and in turn the production of lactic acid is decreased (p. 59), and the elimination of carbon dioxide is augmented (p. 210). This is an important means of regulating the composition of the blood during muscular activity. The substance last mentioned, adrenaline, stimulates the heart to increased activity, increasing both the rate and the force of contractions. It is secreted by the adrenal glands when we are angry, afraid, or otherwise excited, and when the oxygen content of the blood is deficient or tends to become deficient (as in excessive muscular activity). Hence, if other measures fail to maintain an optimal heart rate, adrenaline may be called forth as a last recourse.

23. The regulation of the output of the heart per beat. Increasing the output of the heart per beat has been pointed out as one of the means for increasing the movement of the blood (table, p. 187); decrease would obviously produce the opposite effect. The mechanism for changing this output can be described in a few words:

1. During the stage of relaxation (diastole), the heart fills with blood from the veins. This filling will be rapid if the flow in the veins is rapid, and vice versa.

2. The walls of the heart being flabby or comparatively toneless in diastole, its chambers are distended (because its muscle fibers are stretched) by this inflow from the veins; this distention is greater or less, according to whether the inflow is forceful and rapid or weak and slow. The degree of distention is the measure of the quantity of blood the heart holds in readiness to be expelled.

3. During the stage of contraction (systole) the heart squeezes the blood from its left ventricle into the aorta, the first part of the arterial reservoir. The force with which it contracts is the measure of the quantity the heart can put out at each beat.

4. The force of the contraction, and hence the force with which the blood is squeezed into the aorta, will be great or small, according to the degree of distention of the ventricles at the beginning of systole; that is, if the heart has been greatly distended by the inflow from the veins during diastole, there will be a large volume of blood ready to be expelled, and the pressure producing the distention will stimulate a more forceful emptying. This is the *law of the heart*, and it is ordinarily expressed as follows: "The ability to empty in systole is directly proportional to the fullness of the ventricles in diastole," or "the output in systole is directly proportional to the intake in diastole."

5. As a result, if the flow from the veins into the heart be increased, the output into the aorta will be increased, since the ventricles will be better filled and more forcefully emptied. Now the venous flow, as we have seen previously (p. 174), and the filling of the heart, as we now see, are augmented by an increase in respiratory and muscular activities; hence the output of the heart per beat is increased by speeding up the respiratory and muscular activities. Since muscular activity increases both the venous flow and the respiration, it influences the cardiac output more than does respiratory activity.

We have here, then, a mechanism most wonderfully adapted to adjust the output of the heart to the needs of the tissues and of the muscles in particular. It may be well to review the essential points: Muscular activity calls for an increase in fuel and oxygen (that is, more blood), so that more nutrients and more oxygen may become avail-

able. The oxygen supply is maintained (that is, the blood is kept saturated with oxygen) by increasing the respiration, which in turn is accelerated by the carbon dioxide produced in the muscles. Both the muscular activity and the respiratory movements, which it accelerates, increase the venous flow, and this increases the cardiac output, and this the arterial flow, and this the supply of fuel and oxygen. Hence, the greater the activity of the muscles, the greater the power to act. Of course, a limit would finally be reached, owing to exhaustion of the food supply.

24. The regulation of the output of the heart per minute or other interval of time. In the preceding paragraphs we have studied the mechanisms for changing the rate of the heart and the output per beat, and we have seen that the former may be altered by various stimuli (nervous, chemical, and physical) and the latter chiefly by the rate and pressure of the venous blood flow. It is through the adjustment of these two mechanisms (change in rate of beat and in output per beat) that the output per minute — as stated previously, this is what counts — is adapted to the requirements for keeping the arterial reservoir filled, so that organs in a state of activity may be sufficiently supplied with nutriment. We can best discuss this topic by making reference to the following table:

Rate of Heart Beats per Minute	Output of Heart per Beat (cc.)	Output of Heart per Minute (cc.)	Result	Adjustment Needed
(*a*) 70	100	7000	Normal	None
(*b*) 70	130	9100	Excessive	Inhibition
(*b2*) 50	130	6500	Too little	Acceleration
(*b3*) 54	130	7020	Normal	None; adjusted
(*a*) 70	100	7000	Normal	None
(*c*) 140	50	7000	Normal	None
(*d*) 120	50	6000	Too little	Increased output per beat
(*d2*) 120	58.3	6996	Normal	None; adjusted

In (*a*) is represented an output which met the needs of the organs of the body, while in (*b*) the output was excessive and needed to be reduced by decreasing the rate. This was effected by stimuli through the inhibitory nerve (such stimuli being sent to the heart whenever the arterial reservoir is excessively filled). But the inhibitory effect produced too much slowing, so that in (*b2*) the output fell below normal. In this case, the accelerator nerve quickened the rate and completed the adjustment. Hence, in adjusting (*b*), both inhibition and acceleration were called into play.

Again, in (*d*) the output was too little; here muscular activity was called upon to increase the output per beat. Had this failed, the accelerator nerves might have been brought into action, or there might even have been an outpouring of adrenaline.

We have, then, in the adjustment of the output per minute to the needs of the body a coördination of activities by the inhibitory and accelerator nerves, by the pumping and sucking effects of the respiratory and muscular movements, and by the secretions and waste products of other organs. The effect of each is balanced against or supplemented by some other, so that excessive action in one direction may be counteracted, and so that in case of failure of one mechanism another may assume its rôle. As an analogy, compare the various mechanisms for stopping an automobile: (1) the foot brake; (2) if this fails, the hand brake; (3) then if the car does not stop, leave it in gear and cut off the ignition; and (4) all the preceding having been ineffective, shift to low gear or reverse. In a great emergency, one might be able to do all of the above within the interval of one or two seconds; the body makes the readjustments in the circulation instantaneously and continuously — the foot brake, the hand brake, the ignition switch, the throttle, the gear shift, and the starter are all, at all times, under

constant control, so that there is no interruption in the smooth running of the machinery.

25. The regulation of the outflow from the arterial reservoir; arterial tone. Around the walls of the arteries, especially their smaller branches (the arterioles) which deliver blood from the arterial reservoir (main arteries) to the organs, are circular muscle fibers. Their contraction diminishes the size and capacity of the arterioles, and their relaxation produces opposite changes. As a usual thing these smaller arteries are kept somewhere between extreme constriction and extreme dilation. On a day of moderate temperature, for example, the arterioles of the skin are moderately narrowed by this action of their muscular rings. When exposed to cold, these fibers contract more than usual and so lessen the size of the tube, and during warm weather they relax somewhat and widen it; but ordinarily they are never contracted to their utmost nor are they often completely relaxed.

This condition of sustained activity of the arterial muscles is known as *arterial tone*, and in general any sustained activity of a living cell is spoken of as *tonic activity* or *tone*. Since, as we have seen, the total quantity of blood in the body is not enough to fill completely and distend all the blood vessels when they are widened to their utmost, it follows that the maintenance of arterial tone is essential to that overfilling of the great arteries which supplies the driving force for the flow of blood through the organs. If every arteriole were to lose its tone, blood would flow out of the reservoir more rapidly than the heart could possibly pump it in; we should have somewhat the same condition of affairs as if, in our artificial model (p. 169), the small nozzle which affords resistance to the outflow were removed. Arterial pressure would fall and, the driving force being thus removed, the blood would remain at rest in the capillaries and veins of the organs; the circulation would cease

because blood could not return to the heart to be pumped. The maintenance of arterial tone is consequently no less essential to the circulation than is the beat of the heart itself.

Two means are known by which the contraction of the circular muscle fibers of the arterioles is regulated: (1) by nervous impulses received from the central nervous system by way of the vasomotor nerves, and (2) by chemical stimuli, hormones, received from other tissues by way of the blood.

26. The regulation of arterial tone by nervous action; the vasomotor nerves. The vasomotor nerves are of two kinds, the vasoconstrictors and the vasodilators. These will now be discussed.

1. *Vasoconstrictor nerves.* The circular muscles of the arteries receive nerves which stimulate them to contract; if these nerves are cut, the arteries lose their tone (dilate). We conclude, therefore, that the ordinary maintenance of arterial tone is, in part at least, a function of the nervous system. The muscle fibers of the arteries, in other words, remain in tonic activity because the neurones which supply them with nerve fibers are in tonic activity; for this reason general arterial tone may be increased or decreased by the condition of the central nervous system, by reflex activity, by the nervous shock of surgical operations, or by emotional attitudes.

Neurones which maintain the proper degree of arterial tone are known as *vasoconstrictor* neurones. They obviously do for the circular muscles of the arteries what the motor nerves do for the skeletal muscles and the augmentors do for the heart.

2. *Vasodilator nerves.* Many arteries, however, receive a second set of nerves, which have exactly the opposite function, that is, to make the muscle fibers relax and so lead to a widening or dilation of the artery. These nerves do for the

tonic contraction of the arteries what the inhibitory nerves of the heart do for the heart beat — they diminish or abolish an existing activity and thus give us our second example of inhibitory nerves. They are known as the *vasodilators*.

The vasodilators are not continuously in tonic activity like the vasoconstrictors. They are called into action, reflexly or otherwise, when it is necessary that an organ receive more blood than usual; at other times the vasoconstrictors are free to exert their tonic stimulation and so regulate the flow of blood to the organs.

27. The regulation of arterial tone by chemical stimuli. The most important chemical stimuli and their sources are lactic acid from muscular activity (p. 54), carbon dioxide from all oxidative processes (p. 58), adrenaline from the adrenal glands (p. 75), and pituitary secretion from the pituitary body (p. 84). These substances may be divided into two groups, dilators and constrictors.

1. *Chemical dilators.* Lactic acid and carbon dioxide are acid substances and produce relaxation of the arterioles by virtue of their acidity. They probably play a most useful part in the supply of an increased flow of blood to active muscles. The more active the muscle, the greater the production of these acids; the greater their production, the greater the dilation of the vessels, and hence the more abundant the blood supply and nutrition. In other words, increased activity stimulates increased supplies of fuel for power. These acids also increase the output of the heart, and in this way further aid the circulation of blood in the acting muscle.

2. *Chemical constrictors.* The most important of these are the hormones elaborated in the adrenal and pituitary glands. The former, called adrenaline or epinephrine, has already been described (p. 75). It will be recalled that the presence of adrenaline in the circulating blood directly excites the

arterioles to constrict; that its action on the arterioles is greater in some regions (for example, the abdominal organs) than in others (for instance, the skeletal muscles and skin); that it influences the rate and force of the heart beat; that it is secreted when nervous impulses are dispatched from the nervous system during excitement (fear, anger, and so forth) and whenever the blood is deficient in oxygen. There are also reasons for thinking that one of the internal secretions of the pituitary body (p. 84) may likewise play a rôle in regulating arterial tone and possibly in distributing the blood among the organs. This is a new field of physiology, and the present state of our knowledge justifies only this brief reference to it. Enough is known, however, to show that hormones coöperate with the vasomotor nerves in regulating the flow of blood to the organs, but they probably are called into action only in great emergencies, when the safety of the animal is at stake.

28. Importance of the vascular adjustments in daily life. It is not possible within the limits of the present work to enter further into the mode of action of these factors of vascular coördination. Our main purpose is to show the student that proper coördination is as important in adapting the work of the heart and blood vessels to the hourly needs of daily life as it is in producing purposeful movements of the skeletal muscles. Every change of occupation and activity, every change of surrounding conditions, of temperature, moisture, wind, and so forth, necessitates some special adjustment of the vascular system; and this adjustment is dependent upon the same sort of coördinating action which we have already compared with the operations of a large army. In spite of the fact that we are for the most part unconscious of it, it is none the less a part of our daily life; and the fatigue induced within these vasomotor and hormone mechanisms by their continued activity probably

contributes a large share to that general bodily fatigue which leads us to seek recuperation in rest and sleep.

The apparatus, the operation, and the regulation of the flow of blood and lymph afford an excellent illustration of the fact that the human body is a complex machine. But while we of today look upon it with somewhat less of awe than did our ancestors, and while there is for us less of mystery and more of mechanism in it, we gain, on the other hand, a wholly new revelation of its intricacy and a fresh sense of its marvelous delicacy, beauty, and perfection of adjustment. The mere fact that every one of us carries in his bosom a powerful double force pump of remarkable design, original construction, and extraordinary power, capable, in many instances, of successful and unremitting service for more than three quarters of a century, should be, in itself alone, enough to excite admiration and respect for the entire mechanism of which it is only one part, and to awaken within us a desire to use that mechanism "as not abusing it."

29. Clotting of blood; serum. One of the most important properties of blood is its coagulating, or "clotting," on being withdrawn from the vessels. This consists in converting certain constituents of the blood into a solid mass, the clot, from which the remaining portion separates as a pale-yellow fluid, the serum. The clot is composed of (1) minute fibers (compare a fluff of cotton) which are formed from fibrinogen, one of the proteins of the plasma, and (2) numerous corpuscles which have become entangled among the fibers. It serves the useful purpose of a dam, checking the loss of blood when our flesh is cut or otherwise injured so as to open blood vessels. The blood of healthy persons clots in about five minutes; but the process is delayed in calcium deficiency, jaundice, and hæmophilia. Such diseases endanger life, owing to the tendency to bleed freely.

CHAPTER X

RESPIRATION

1. The fundamental act of respiration.[1] We have found in studying the chemical changes which underlie cellular activity (Chapter IV) that muscle fibers and gland cells and, we may now add, nerve cells take in oxygen and give out carbon dioxide. This *cell breathing* is the essential act of *respiration*, for respiration is only another name for the oxidative processes of the living body. Respiration of this kind (and of this kind only) is universal among living things. The one-celled animal, for example, takes its oxygen directly from the free oxygen of the water in which it lives, and discharges its carbon dioxide into the same surrounding medium. Every one of the thousands of cells of which the human body is composed repeats this same process, taking its oxygen from and discharging its carbon dioxide into its surrounding medium — in this case the lymph. The breathing movements, which renew the air in the lungs, and the circulation of blood, which affords the channel of communication between the lungs and the tissues, are merely accessory mechanisms rendered necessary by the distance of the cells and the lymph from the surface of the body. Their principal function is to keep the lymph supplied with oxygen

[1] In the higher animals and man, two processes are involved as follows: (1) *internal respiration, cell breathing*, or *tissue respiration*, which is the gaseous exchange between the tissues and the lymph; and (2) *external respiration*, which is the gaseous exchange between the lymph and the atmosphere, effected by the circulation of the blood and the ventilation of the lungs. The last mentioned is brought about by the expansion and contraction of the thorax (breathing movements) and is often referred to as *pulmonary ventilation* or breathing.

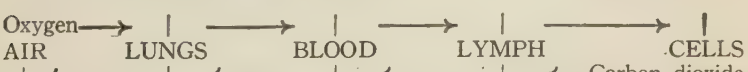
and to remove from it the carbon dioxide. In other words, breathing, though ministering to respiration, is not respiration itself.

2. The quantity of oxygen and of carbon dioxide in the lymph surrounding the cells of the body. The cell is the true seat of oxidation. Within its imperfectly understood mechanism are found the conditions which lead to the union of oxygen with the proteins, the carbohydrates, and the fats of the food.

The cell draws oxygen from the surrounding lymph very much as a burning match draws oxygen from the surrounding air. The amount of oxygen dissolved in the lymph is generally comparatively small and consequently would be removed altogether were it not constantly renewed from the blood, which in turn obtains fresh supplies of oxygen in the lungs.

For similar reasons the lymph must be relatively rich in carbon dioxide, since it is this fluid which directly receives the gas (in solution) from its source of manufacture, the active cell.[1] The concentration of this gas in the lymph is being diminished constantly, owing to its diffusion into the blood, which in turn carries it to the lungs to be discharged.

The transference of oxygen and carbon dioxide through the body may be presented graphically as follows:



3. The quantity of oxygen and of carbon dioxide in arterial blood. It is through the lungs that the body as a whole receives its oxygen and discharges its excess of carbon

[1] The gases oxygen and carbon dioxide are, of course, dissolved in the liquid lymph and blood plasma. A liquid exposed to a gas absorbs or dissolves the gas. Thus 100 cc. of water, when exposed to atmospheric air at 0° C., dissolves 4 cc. of oxygen and 2 cc. of nitrogen.

dioxide. Consequently arterial blood contains more oxygen and less carbon dioxide than venous blood. The actual figures are as follows:

	Oxygen	Carbon Dioxide	Nitrogen
100 cc. of arterial blood contains . . .	20 cc.	38 cc.	1–2 cc.
100 cc. of venous blood contains . . .	8–12 cc.	45–50 cc.	1–2 cc.

These figures apply to the whole blood, that is, to plasma and corpuscles; but what is true of the whole blood is true in a general way also of the circulating plasma, which consequently enters the capillaries [1] relatively rich in oxygen and poor in carbon dioxide, thus presenting exactly the reverse composition, in respect to these gases, of that found in the lymph surrounding the living cells.

4. The exchange of oxygen and carbon dioxide between the lymph and the blood plasma. In the capillary regions of all parts of the body except the lungs we have two fluids, the lymph and the blood plasma, containing very different amounts of oxygen and carbon dioxide and separated from each other by the exceedingly thin membrane of the capillary wall. Under such conditions both gases will tend to equalize, and each gas will pass through the membrane from that liquid in which it is more abundant to that in which it is less abundant; that is to say, the oxygen will pass from the blood plasma, in which it is abundant, to the lymph, in which it is scarce; and the carbon dioxide will pass in the other direction, from the lymph to the blood plasma (see Fig. 80). Hence the blood enters the veins richer in carbon dioxide and poorer in oxygen than when it left the arteries.

[1] The total time consumed by the blood in passing from the capillaries of the lungs through the heart to those of the rest of the body seldom exceeds five or six seconds. Hence the amount of the gases in the blood entering the capillaries, for example, of a muscle is practically the same as in the blood leaving the lungs.

5. The red corpuscle as a carrier of oxygen. The blood plasma, under the conditions of temperature and pressure to which it is exposed, can hold only a small amount of oxygen, too little to meet satisfactorily the demands of the resting tissues and utterly inadequate for the much greater needs of the active tissues. This difficulty is met and the oxygen-carrying capacity of the blood vastly increased by the peculiar properties of the coloring matter, or pigment, of the red corpuscles. This substance, known as hæmoglobin, readily forms with oxygen a compound (*oxyhæmoglobin*) *whenever the amount of oxygen is high in the medium surrounding it*; if, however, much oxygen is removed from its surrounding medium, the oxyhæmoglobin breaks up or dissociates into hæmoglobin and free oxygen. Applying this to the conditions in the capillaries, we find that 100 cc. of arterial blood contains less than 1 cc. of free oxygen in the plasma, but about 19 cc. of oxygen combined in the oxyhæmoglobin of the red corpuscles. When the blood enters the capillaries of living tissues, oxygen passes, as we have seen, from the plasma into the lymph, so that the oxygen content of the plasma is reduced. When this reduction goes below a point which is quickly reached, dissociation of the oxyhæmoglobin occurs, and the oxygen thus set free in the plasma is drawn away by the lymph, from which it is in turn drawn by the cell, the real seat of oxidation.

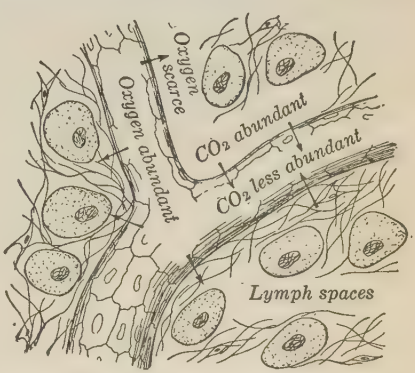


FIG. 80. The exchange of oxygen and carbon dioxide between the blood and the lymph in the tissues

The amount of oxygen mentioned above (20 cc. per 100 cc. of blood) is the maximum that blood can hold under the usual conditions of atmospheric pressure and at the temperature of the body. This is the point of saturation; expressed as a ratio it is 1:5. When the blood leaves the lungs, it contains this proportion of oxygen. It is kept practically constant by a delicate adjustment of the breathing movements to the needs of the body, so that the lungs may receive from the air a supply of oxygen ample to fully oxygenate the blood. Since the blood in its passage through the lungs absorbs this maximum of oxygen, it follows that neither deeper nor more rapid breathing can increase the ratio of 1:5. Accordingly the quantity of oxygen carried by the blood in a minute can be increased only by augmenting the amount of blood pumped through the lungs in a minute; and, similarly, the quantity of oxygen carried to an organ in a minute can be increased only by augmenting the amount of blood flowing through that organ in a minute. We will discuss in subsequent paragraphs the coördination of respiratory and cardiac activities. It is sufficient for the present to emphasize (1) that the breathing movements are adjusted to keep constant the quantity of oxygen per 100 cc. of blood, and (2) that the output of the heart is adjusted to regulate the total quantity of oxygen received by an organ in a minute.

6. The consumption of oxygen in the tissues. The quantity of material oxidized in the cells of the body depends chiefly, indeed under ordinary conditions of life it depends entirely, on the amount of work these cells are doing. To put the matter in another way, the cells always contain a certain quantity of oxidizable material formed by the chemical changes going on within them; during activity of the cell there is a marked increase of oxidizable material (possibly the result of the cleavages described in Chapter IV), and

for this reason there is a corresponding increase of oxidation in the cells. It follows that, in general, cell oxidation can be increased only by increasing cell activity; it cannot be increased by the mere act of deep breathing. "We may lead a horse to water or fetch water to a horse, but we cannot make him drink." The assertion, too frequently heard, that some special form of breathing movement leads to more efficient oxidation of wastes throughout the body betrays lamentable ignorance of this fundamental fact of physiology. This, however, is not denying that one type of breathing movement may still be preferable to another, nor affirming that deepened breathing may not sometimes be desirable. Breathing movements accomplish other things than supplying oxygen to the blood, and we may now proceed to study their physiology.

FIG. 81. Two adjacent alveoli of the lung

Showing the air cells

7. Structure of the lungs. In Chapter II the anatomical relations of the air passages (*trachea, bronchi*, and so forth) and lungs have been described. The student at this point should consult especially Fig. 6 (p. 17) in order to obtain a clear idea of the structure of the lungs. The bronchi which enter the lungs divide, much as do the ducts of a gland, and their ultimate branches end in the *alveoli*, which, like those of a gland, consist of a single layer of cells, but in this case of *very thin, flattened cells*. Fig. 81 shows two of these alveoli dissected, and Fig. 82 a section taken lengthwise through the same. Connective tissue binds together the alveoli and bronchial tubes, thus forming the lobes of the lungs. In this connective tissue — and hence between the alveoli — are the larger blood vessels, branches of the pulmonary artery and pulmonary veins. The arterioles supply an exceedingly close network of capillaries, which are in direct

contact with the lining cells of the alveolus, so that the blood in these capillaries is separated from the air in the alveolus only by the thin capillary wall and the equally thin layer of flattened alveolar cells. Under these circumstances the exchange of oxygen and carbon dioxide takes place readily between the air in the lungs and the blood in the capillaries. Finally, the absorbing surface of the alveolar wall is greatly increased by its arrangement in the form of pits, or *air cells*,[1] as shown in Figs. 6, 81, and 82.

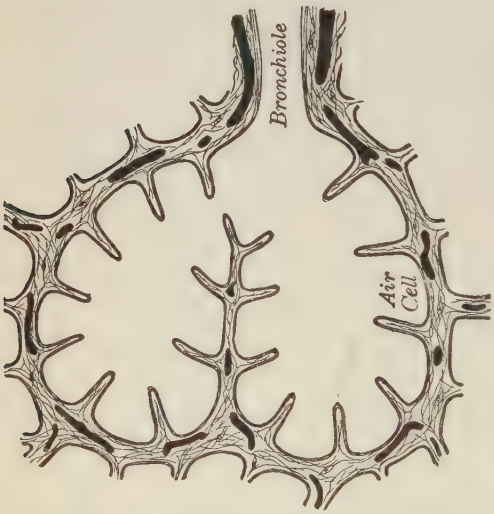


FIG. 82. Diagram of a longitudinal section of two alveoli with their common bronchiole, showing, in black, the larger blood vessels in the connective tissue

8. The purpose of the movements of breathing. As the blood is constantly giving up carbon dioxide to, and taking oxygen from, the air of the lungs, this air would soon cease to be of use in purifying the blood were it not for the breathing movements, whose function is to replace the vitiated air within the lung with pure air from without. Breathing is, accordingly, an act of *ventilation* of the lungs, and it is the stoppage of this ventilation which produces suffocation, or asphyxia.

9. Mechanics of the breathing movements. A knowledge of the mechanism of the breathing movements is of much

[1] The word "cell" is here used to represent a hollow space, and not with its usual histological meaning.

practical importance, especially in hygiene, and may be understood without great difficulty by the study of the model shown in Fig. 83. The trachea and the bronchi are represented by the glass tube, *a*, and the lungs by a rubber bag, *l*, at the end of the tube. The lungs lie in the large *air-tight* thorax, which incloses the *pleural*, or *thoracic*, *cavity* (p. 13). This thoracic wall is represented in the model by a glass bell jar closed beneath by a sheet of thick rubber, *d*. The cavity of the bell jar represents the pleural cavity, and the rubber represents the diaphragm (see Fig. 6). The condition of the lung in the pleural cavity may be still further imitated in the model by fastening the *inflated* rubber bag tightly into the jar.[1] The rubber bag remains moderately inflated within the air-tight cavity of the bell jar. In the body the distended lungs virtually fill those portions of the thoracic cavity not occupied by the heart, great blood vessels, and other organs.[2]

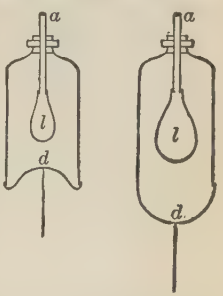


FIG. 83. Model of the action of the thoracic walls and lungs in respiration (see section 9)

Now enlarge the "thoracic cavity" of the model by pulling downwards on the sheet of rubber which represents the diaphragm. The "lungs" within will expand while air is sucked through the glass "trachea" and mixes with that in the model "lungs." When the pull is released, the "diaphragm" rises, thus diminishing the size of the "thorax" and so forcing air out of the "lungs." In this way the mechanism of the ventilation of the lungs may be imitated in essential particulars.

[1] Loosen the rubber stopper and inflate the rubber bag; while the bag is thus inflated, push the rubber stopper down into the neck of the bell jar.

[2] The student is warned against supposing that the pleural cavity is a large space filled with air; in this respect the model is misleading, since the lungs and other organs virtually fill the thoracic cavity.

In life the pleural cavity is enlarged during inspiration by two mechanisms: (1) the contraction of the diaphragm and (2) the elevation of the ribs. Both these movements are effected by the action of skeletal muscles. The understanding of the elevation of the ribs need give no difficulty; muscles, some of which are shown in Fig. 14, pull upward on the ribs, and the attachment of the ribs to the vertebral column and the breastbone (sternum) is such that when they are raised the diameter of the thorax is increased dorsoventrally and from side to side. The diaphragm, on the other hand, is a kind of circular muscle with a central fibrous or tendinous portion from which the bundles of muscle fibers radiate outward to its edges. Any shortening of these fibers evidently diminishes the diameter of the diaphragm; and because of its form (that of a dome directed upward into the thoracic cavity), contraction of this muscle must increase the size of the lower thorax.[1]

There are three typical modes of breathing. (1) *The predominantly costal, or rib, breathing.* Here the diaphragm is but little used. It is the type characteristic of persons who impede movements of the lower ribs and abdomen with constricting clothing, such as tight corsets. (2) *The predominantly abdominal.* Here the ribs are little used, while the diaphragm does most of the work, the abdominal muscles being relaxed so that the abdominal wall has its maximum of movement. This type of breathing involves great relaxation of tone of the abdominal muscles, which is a serious

[1] The action of the diaphragm is often described as increasing the anteroposterior (head to foot) dimension of the thorax; but this can happen only when the diaphragm is free to descend, and it can descend only when, by displacing downward the contents of the abdominal cavity, it causes the well-known respiratory movements of the abdominal wall. These abdominal movements may, however, be prevented by the simultaneous contraction of the abdominal muscles. In this case the diaphragm cannot descend, and its contraction can only raise the lower ribs, to which it is attached. The mechanism in these two methods of using the diaphragm is clear from Fig. 84.

disadvantage. (3) *The lateral costal.* Here the abdominal muscles act at the same time as the ribs and the diaphragm. This form of breathing produces the highest pressures on the contents of the abdominal cavity and maintains the tone of the abdominal walls without diminishing the filling of

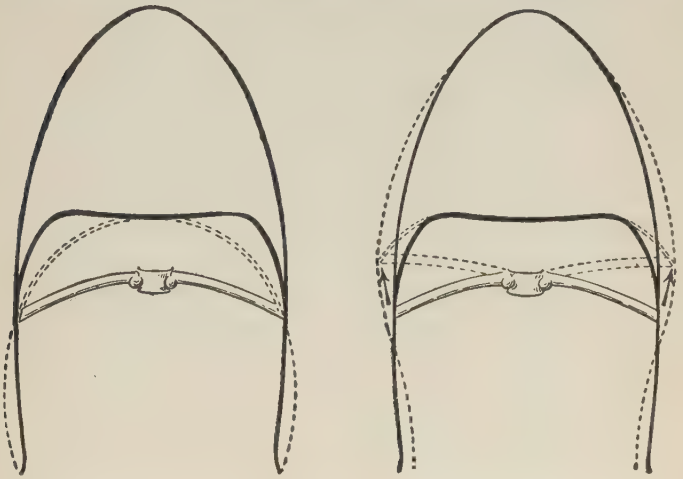


FIG. 84. Action of the diaphragm in abdominal and in lateral costal breathing

Solid lines represent position of body wall, diaphragm, and ribs during expiration; dotted lines, the same during inspiration. The left-hand figure represents abdominal breathing, the diaphragm becoming more convex, displacing downward the abdominal viscera and forcing outward the abdominal body wall. In the lateral costal type the diaphragm raises the lower ribs, and the abdominal walls may actually move inward, owing to the contraction of their muscles

the lungs and the resulting efficiency of the oxygenation of the blood. It also forces the use of the upper ribs to a much greater extent than does the predominantly abdominal type of breathing (Fig. 84).

It is seldom that one or another of these types is used in its entirety, and the advantages of one form over another are often greatly exaggerated. The following statements

may, however, be taken as summing up the essential practical points concerning the breathing movements:

1. The breathing movements should be such as to use all portions of the lungs. In the abdominal type there is little or no movement of the upper thorax. The result is that the apical, or upper, lobes of the lungs do not share in the enlargement and contraction of the lungs; they are poorly ventilated, their lymph current — which largely depends upon these movements — becomes sluggish, and because of these unfavorable physiological conditions there is greater liability to disease. More than 60 per cent (some observers claim as many as 80 per cent) of the beginnings of pulmonary consumption are found in this portion of the lung, and this is believed to be due to the lack of movement which results from the failure to use the upper thorax.

2. Actual study of the breathing movements in people who have not worn constricting clothing indicates that the enlargement of the thorax in inspiration is effected by the approximately equal action of the diaphragm and of the muscles which elevate the ribs.

3. The abdominal muscles should to some extent contract with the diaphragm. This is especially important in those whose occupation is more or less sedentary, as it is the most convenient means of giving to these muscles the use which is essential to the maintenance of their strength and tone, which are essential to hold up the organs of the abdominal cavity in their normal position (consult page 394).

4. There are good reasons for thinking that it is important to develop properly the muscles of the upper thorax, and especially those which lie in the triangle between the root of the neck, the collar bone, and the shoulder blade. When these muscles are not developed, especially in thin people, the wall of the thorax in this region sinks inward during inspiration; under these circumstances the apical lobes no

longer share in the expansions and contractions of the lungs, and imperfect ventilation of this part of the lung results.

10. Secondary effects of the breathing movements. The student will now be better able to understand the part taken by the breathing movements in facilitating the return of blood and lymph to the heart. It will be recalled that the large vessels, which drain the blood and lymph from all parts of the body, lie in the thoracic cavity between the lungs (see page 27). Hence, the enlargement of the thorax during inspiration sucks blood and lymph in toward the great veins by the same process that it sucks air into the lungs. Especially in the case of the flow of lymph is this a most important factor. Moreover, in the lymphatics of the lungs, situated as they are entirely within the thorax, the movements of the lungs during respiration pump the lymph onward; this is of special importance. Much of the invigorating effect of muscular exercise, popularly ascribed to better oxygenation of the blood and tissues, is really attributable to the greatly improved flow of lymph from all organs which results from the deepened respiration that takes place during muscular activity.

11. The automatic respiratory center and its regulation by the carbon dioxide of the blood. The muscles of the diaphragm and those of the ribs, like the biceps and other muscles which act upon the skeleton, are stimulated to contraction by nervous impulses from the brain and spinal cord. Every movement of respiration is called forth and regulated, in accordance with the needs of the body at the time, by the coördinated action of a number of nerve cells. Those which are most intimately concerned with respiration are found in different parts of the central nervous system, from the lower portion of the brain to the end of the first half of the spinal cord, inclusive. Since the intercostals, the diaphragm, and certain other muscles must work in a coördinated manner,

it is necessary that their motor nerves should be under the control of another special group of nerve cells. The location of such a group has been demonstrated experimentally in the lower portion of the brain. This is called the respiratory center, and from it stimuli are sent out to appropriate cells of the cord, which in turn excite the respiratory muscles to contract.

The respiratory center, like the heart (see page 186), is automatic. This means that its nerve cells periodically (usually eight to twenty times a minute) discharge impulses to the respiratory muscles independently of any stimulation either by afferent nerves or by other means. Like the beat of the heart, however, this automatic action is regulated in various ways. A dash of cold water on the skin reflexly changes the character of respiration; coughing and sneezing are similarly examples of reflex modification of the breathing movements; during vigorous muscular activity the change in composition of the blood by the addition of waste products deepens and quickens the breathing; last, but not least, one of the most important discoveries of recent years has shown that the carbon dioxide of the arterial blood going to the respiratory center is a most important agent in regulating the automatic activity of this center. No sooner does the carbon dioxide of the blood increase than this center discharges its nervous impulses more powerfully, thus deepening the breathing. An increase of from 3 to 4 per cent in the carbon dioxide of the arterial blood doubles the quantity of air breathed per minute. From this it is evident that the high content of this gas in arterial blood (see page 200) serves the very important function of adjusting the work of this center to the needs of the body. Whenever, for any cause, the respiratory movements no longer adequately ventilate the lungs — so that carbon dioxide discharged into the blood in its course through the body is not completely removed in the lungs — the consequent increase of this gas

in the arterial blood excites this center to greater activity, with a resulting increase of breathing and more efficient ventilation of the lungs. We may recall, in this connection, the warning given in Chapter VI against supposing that a waste product of the activity of one organ is necessarily harmful; for carbon dioxide is the chief waste of the body, yet it is most important that the amount usually present in arterial blood be maintained. Only the excess above this amount is injurious, and usually an excess is prevented automatically by the increase in breathing movements which it produces.

12. The circulation as an essential part of the mechanism of respiration. The consumption of oxygen and the production of carbon dioxide thus involve an interchange of these gases between the blood and the tissues (internal respiration) on the one hand, and between the blood and the air in the lungs (external respiration) on the other. But to carry out these gaseous exchanges a third factor is obviously necessary, namely, a means of communication between the two, so that the oxygen absorbed in the lungs may be carried to the tissues, and the carbon dioxide produced in the tissues be carried back to the lungs. This communication is provided, as has been shown in earlier chapters, by the circulation, which thus becomes an essential part of the respiratory mechanism.

We have already seen that under the most varying conditions 100 cc. of arterial blood normally contains approximately 20 cc. of oxygen and 38 cc. of carbon dioxide, and that this is practically all the oxygen this amount of blood can hold. From this it follows that, so long as the amount of blood pumped by the heart in a given time remains constant, no more oxygen will be carried to the tissues, even if we breathe more deeply. In other words, *increased ventilation of the lungs without any accompanying increase in the rate and force of the heart beat will not supply more oxygen*

to the tissues. The beat of the heart is as important to proper *tissue respiration*[1] as are the breathing movements; and we find accordingly that these two events are closely coördinated. Greatly increased tissue respiration is invariably accompanied by increased work on the part of the heart.

A large number of measurements of the *respiratory exchanges*[1] under different conditions and activities of our life has shown that these are increased by the taking of food, by exposure to cold, by awaking from sleep, and, above all, by muscular activity. Exposure to cold acts by causing us to move about more briskly, or, if we do not, by causing us to shiver, so that this really becomes a case of muscular activity. The same thing is true of awaking from sleep. We may therefore make the general statement that muscular activity is the most important agent of life which increases tissue respiration.

And this increase is at times very great. Even the muscular activity necessary to maintain the erect position in sitting and standing, as compared with the complete relaxation of sleep, doubles the gaseous exchange; gentle exercise (a walk of three miles an hour) more than doubles that of rest; and vigorous, yet by no means excessive, exercise will increase it tenfold. These increases mean corresponding, though not absolutely proportionate, demands on the heart and emphasize the importance of keeping that organ in an efficient working condition. Breathlessness, for example, usually indicates, in part at least, that the heart fails to respond properly to the demands made upon it, these demands being greater than it can meet without undue fatigue; it is a warning that we are pushing the heart too hard, a warning which we shall do well to heed. Generally it is also a warning that we habitually do not get sufficient muscular activity; the heart fails to meet the emergency of

[1] That is, oxygen absorbed and carbon dioxide discharged in a given time.

some unusual exertion because all along it has not been kept in proper training; so that while we should, as stated, heed the warning not to push the heart so hard for the time being, we should also act upon the equally important warning that it needs practice or training — a training which can be given only by reasonable, regular muscular activity.

Physical training is therefore a training not only of the muscles but also of the heart. But this is not all. *The work of the circulatory and respiratory mechanisms must be adjusted or coördinated, the one to the other.* When, for example, the deepened breathing movements accompanying muscular activity rush the blood back more rapidly to the heart (p. 173), it becomes necessary for the heart to adjust the character of its beat to the new conditions; and this adjustment is effected through the joint action of nervous, chemical, and mechanical stimuli.[1] Time is, however, required to make the adjustment, so that it is wise to "warm up" gradually to more vigorous exercise. We can also understand how by physical training this process of adjustment comes to be shortened, for we have not only trained the heart by giving it more work to do but we have also trained those portions of the nervous system which regulate its beat.

[1] The following is presented as a review of the various factors involved:

Muscular activity must be accompanied by
- *A.* Increased action of the heart, which is brought about by
  1. Increase in carbon dioxide and lactic acid from the muscles;
  2. Reflexes from sensory nerve endings in the muscles and joints;
  3. Increased venous return (the pumping effects of muscles and joints);
  4. Stimuli from the nervous system by way of the accelerator nerves;
  5. Adrenaline, secreted when the oxygen supply is markedly decreased.
- *B.* Increased respiration, which is brought about by
  1. Increased carbon dioxide from the muscles;
  2. Reflexes from sensory nerve endings in the muscles and joints;
  3. Stimuli from the nervous system to the respiratory center.

An increase in respiration directly increases the output of the heart through promoting the return of the blood by the pumping action of the thorax, the augmented venous return leading to (1) a greater output per beat due to the better filling and emptying, and (2) quickened rate of beat due to the reflex acceleration following the increased filling.

CHAPTER XI

EXCRETION

1. The organs of excretion. The student now realizes that the activity of the body is accompanied by the production of wastes, and also understands the necessity for their removal. The most abundant waste product of the body, carbon dioxide, is a gas and is excreted by the lungs; others, notably urea and other waste products of the proteins, are dissolved solids and are removed from the blood to some extent by the large intestine and the sweat glands, but chiefly by the kidneys.

A number of organs thus perform the work of excretion, but four of them — namely, the *lungs*, the *kidneys*, the *large intestine*, and the *skin* — are of greater importance than all others. Of these four the lungs and kidneys are far more important than the intestine, and any one of these three is more important than the skin.

2. Essential and incidental excretion by organs. An organ may be essential to the proper removal of a given waste, or it may remove the waste product only incidentally in performing its usual and chief functions. Thus the skin removes a small amount of carbon dioxide from the body merely because a certain amount of this gas diffuses from the blood as it flows through the skin. It is not necessary to the health of the body that the skin should excrete this carbon dioxide, for the lungs are quite capable of doing this and would do so if for any reason such excretion through the skin were prevented. Without the lungs, on the other hand, the carbon dioxide would rapidly accumulate in the

blood and cause death. The lungs are essential to the removal of this waste; the skin is not. Similarly, the perspiration contains small amounts of urea and other wastes which are removed in large quantities by the kidneys. It is not necessary that the skin should remove any of these, for the healthy kidney can and does, when necessary, remove them. Small quantities of them appear in the perspiration because they are in the blood from which the perspiration is formed, and because the cells of the sweat glands allow them to pass through just as the skin allows the passage of carbon dioxide.

These considerations are of practical importance in the hygiene of the skin. It is not necessary in healthy individuals to induce perspiration merely to remove waste products from the body. If the human skin, like that of the cat and the dog, contained no sweat glands, the waste products would still be thoroughly removed; and in cold weather, when less perspiration is secreted, the excretion of waste is as complete as in warm weather, when perspiration is abundantly secreted. On the other hand, perspiration, though not secreted to rid the body of wastes, nevertheless contains wastes, which accumulate upon the skin. Hence the need of bathing, as a matter both of health and of decency.

The chief wastes leaving the body, and their main channels of excretion, are given in the following table, *incidental* excretions being given in *italics*:

Lungs: carbon dioxide, *water.*
Kidneys: urea, uric acid, and other compounds; salts, water.
Intestine: bile pigments, *nitrogenous compounds.*
Skin: *urea, salts, water.*

The structure and action of the lungs and intestine have already been described, so that we have remaining for study the kidneys and the skin.

3. Structure of the kidneys. Each kidney is a bean-shaped gland whose duct, the *ureter*, runs to the urinary *bladder* (Fig. 85), which in turn empties through the *urethra*. As the ureter enters the kidney, at the center of the depression in that organ, it expands to form a basin, known as the *pelvis of the kidney*. Into this basin open the hundreds of glandular tubules of which the bulk of the kidney is composed (Fig. 86). Each tubule, like the alveoli and ducts of the gland described in Chapter III, consists of a single layer of cells, which wall off the blood and lymph from the lumen of the tubule. *The formation of urine by the kidney is essentially an act of secretion.*

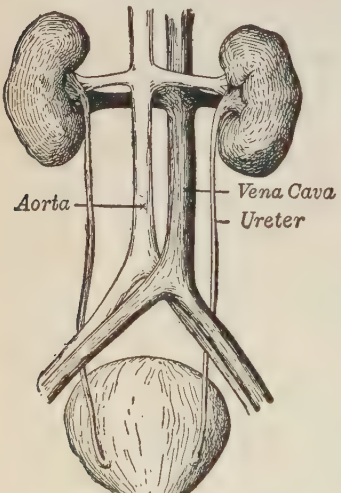


FIG. 85. Dorsal aspect of the kidneys, ureter, urinary bladder, and the abdominal aorta and vena cava

4. The secretion of urine. The urine is secreted continuously from the blood, at one time more rapidly than at another, but under normal conditions never ceasing altogether. Passing down the tubules, it collects in the upper portion of the ureter, and successive peristaltic waves carry it from this point to the urinary bladder, an organ with muscular walls, in which the urine accumulates and from which it is from time to time discharged.

In one very important respect, however, secretion by the kidney presents a sharp contrast to secretion by the stomach and the submaxillary gland. While an adequate blood supply to the two latter organs accompanies secretion and, indeed, is necessary to maintain the secretion for any length

of time, yet these organs secrete only as they are stimulated to activity by their nerves; merely increasing their blood supply does not produce increased secretion. In the case of the kidney there seem to be no secretory nerves, and the activity of the gland seems *to be determined to a large extent by the quantity of blood flowing through it.* Anything which increases this quantity of blood increases the quantity of urine secreted; anything which diminishes it lessens the amount of urine secreted.

FIG. 86. Vertical section of the kidney. Diagrammatic

The tubules (*a*) of the gland open, through the papillæ (*b*, *b*) and the pelvis (*c*), into the ureter (*d*)

In the everyday experience of healthy people the activity of the kidneys is chiefly affected by three things: namely, (1) external temperature — more urine is secreted in a cold than in a warm environment; (2) the quantity of water drunk; and (3) the quantity of food, and especially of protein food, eaten. All three of these agents, however, produce their results, largely if not entirely, because of their influence upon the flow of blood through the kidney. Thus exposure of the skin to cold causes a constriction of the arterioles of the skin and a compensating dilation of those of internal organs, the kidneys included. More blood flows through the kidneys and more urine is secreted. Much the same thing is true of the absorption of water and of protein food, for both these conditions cause a widening of the arterioles of the kidney.

Changes in the quantity of the urine secreted are, generally speaking, only changes in the amount of water rather than in the amount of urea and other dissolved wastes.

Certain constituents of the urine, however, are not very soluble, so that it is not well to diminish unduly the intake of water, which is the only solvent of these substances in the urine. A scanty secretion of urine during the day is, in general, a distinct indication, especially in warm weather, that insufficient water is being taken. Many persons drink too little water.

5. The structure of the skin. The skin is an organ which performs several functions, the most important being (1) that of protecting the underlying structures from drying and from mechanical injury; (2) that of helping to maintain the constant internal temperature of the body; and (3) that of receiving the external stimuli (pressure, heat, and cold), which effect reflexes of various kinds to adapt the body to its enviroment. Incidentally, as we have seen, the skin is an organ of excretion. We may therefore describe its structure and excretory function in this connection, reserving the study of its other functions for Chapters XII and XIV.

The skin consists of an outer layer, the *epidermis*, and an inner layer, the *dermis*, *cutis*, or *corium* (Fig. 87). The dermis consists of connective tissue richly supplied with blood vessels, lymphatics, and nerve fibers, together with sense organs of touch, heat, and cold. The fiber bundles of the connective tissue are most dense near the epidermis; in the deeper portions the network is loose and the lymph spaces larger, the connective tissue of the dermis passing insensibly into the subcutaneous connective tissue.

The cells of the more open portions of the dermal network, and especially those of the subcutaneous tissue, store up more or less fat within their cytoplasm. The subcutaneous tissue, indeed, is one of the most important organs in the body for the storage of fat. Connective tissue in which large amounts of fat are stored is known as *adipose tissue* (see page 257).

The outer surface of the dermis is not flat, but contains moundlike projections known as *papillæ*, which project into the overlying epidermis. Some of these papillæ contain nerve endings of the sense of touch, while others contain capillaries, which are found also in other portions of the dermis. The dermis is the vascular organ of the skin, blood vessels being entirely absent from the epidermis (see Figs. 90, 93).

FIG. 87. Cross section of skin

A, horny layer of epidermis; *B*, deeper layer of epidermis; *C*, duct of sweat gland; *D*, dermis; *E*, subcutaneous connective tissue (p. 11). The blood vessels are injected to show black. (Cf. Fig. 93)

The epidermis consists of many layers of cells, — a hundred or more layers on the palms of the hands and the soles of the feet; in other places less exposed to pressure or friction the layers may not exceed twenty. The deeper cells (that is, those nearer the dermis) are alive and in process of active growth and multiplication. The outer layers, which are farther from the dermis with its blood supply, and nearer the surface with its exposure to drying, degenerate and are gradually transformed into dead, flattened, horny scales which, packed together, form the *horny layer*. These scales are being constantly rubbed off and their loss made good by the growth and multiplication of the living cells beneath. Such a covering or lining is well fitted for surfaces which are exposed to friction or drying, since it is tough and almost impervious to water. The endings of nerve fibers are found in the lower layers of the epidermis.

The hairs, the sweat glands, and the nails are modified portions of the epidermis. Of these the hairs and the sweat glands are of sufficient importance to merit some description.

6. Structure of a hair and a hair follicle. A hair grows from the bottom of a pit, the hair follicle, which extends downward into the dermis or even into the subcutaneous tissue. Microscopic examination shows that this follicle is lined with a continuation of the epidermis, just as a gland of the stomach or intestine is lined by an ingrowth of the cells of its surface. At the bottom of the follicle is a papilla, and the hair which grows out from this papilla to the surface bears to the cells of the papilla the same relation that the horny layer of the epidermis bears to the similar underlying cells. We accordingly find that the hair is composed of horny scales closely pressed together into the well-known threadlike structure.

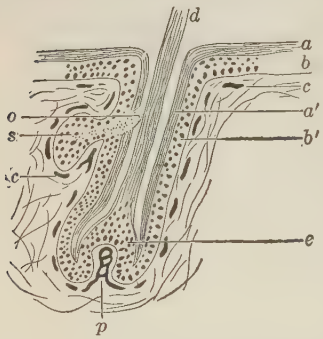


FIG. 88. Hair and hair follicle

a, horny layer of epidermis. *b*, layer of living, growing cells extending (*b'*) into the hair follicle, at the bottom of which it forms the mass of growing cells (*e*) over the papilla (*p*) with its knot of capillaries; the growth, multiplication, and transformation of these cells into horny fibers forms the shaft of the hair (*d*). *c*, capillaries in the dermis. *s*, a sebaceous gland discharging its oily secretion (*o*) into the follicle to lubricate the hair and the horny layer of the skin

Into the hair follicle one or more *sebaceous glands* discharge an oily secretion (*sebum*), which lubricates the hair and the horny layer of the epidermis, and so prevents drying and chapping and preserves flexibility and elasticity (Figs. 88 and 89). The secretion of these glands is sometimes retained in the duct or the hair follicle and thus produces blemishes called blackheads. These are most common at the sides of the nose and behind the ears, where the sebum is most abundant.

7. The sweat glands are tubular prolongations of the epidermis through the dermis into the subcutaneous tissue. Here the tube becomes larger and very much coiled, forming the secreting recess, which is richly supplied with blood vessels and also receives nerves. (See Figs. 90 and 93.)

8. The secretion of the perspiration, like the secretion of the gastric juice, is under the control of the nervous system. When the nerves going to the sweat glands of a given area of skin are cut or otherwise injured, the secretion of perspiration ceases over that area; and the appearance of cold beads of perspiration as a result of fright shows how events taking place in the nervous system may excite these glands to activity apart from the presence of their usual stimuli — the application of heat to the skin and the liberation of heat within the body by muscular and other activities. The distinction should be made between the so-called "sensible" and "insensible" perspiration; the latter description is applicable when the water of perspiration evaporates as fast as secreted, and the former when the water does not evaporate so rapidly and hence remains for a time on the surface of the skin. In either case the dissolved solids (salts, urea, and other compounds) remain on the skin and need to be removed by bathing.

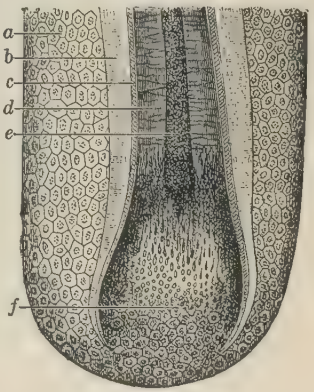


FIG. 89. Magnified section of the lower portion of a hair and hair follicle

a, membrane of the hair follicle, cells with nuclei and pigmentary granules; *b*, external lining of the root sheath; *c*, internal lining of the root sheath; *d*, cortical or fibrous portion of the hair shaft; *e*, medullary portion (pith) of shaft; *f*, hair bulb, showing its development from cells from *a*

9. Value of profuse perspiration in the care of the skin. While the skin is not primarily an organ of excretion, the perspiration contains a certain amount of waste substances and salts, which are left by the evaporation of the water upon the surface and, to some extent, in the mouths of the ducts of the sweat glands; the latter is especially the case when evaporation takes place about as rapidly as the perspiration is discharged. When the secretion of perspiration is more abundant, as during muscular work or at very high temperatures, or, in general, when it does not evaporate as rapidly as discharged, the accumulation of solids in the ducts of the glands is washed out. For this reason a vigorous perspiration followed by a bath is a useful hygienic measure in the care of the skin, although it is not necessary, as is sometimes supposed, in order to secure the efficient elimination of wastes from the blood.

FIG. 90. Sweat gland (highly magnified)

Note the coiled form of the tube in the subcutaneous tissue. (Cf. Fig. 93)

10. The skin as an organ of absorption. While it is true that water as perspiration may readily find its way out through the skin, such escape is effected chiefly by the sweat glands, which are under the strict control of the nervous system. Apart from this the skin is virtually water-tight; and, oiled as it is by the secretion of the sebaceous glands, it serves both to keep in the water which forms so important a part of the tissues, and also to keep out water which might otherwise soak into the body, as, for example, during bathing. This waterproof characteristic also makes it next to impossible for us to absorb food materials by way of the skin.

CHAPTER XII

THERMAL PHENOMENA OF THE BODY

I. The Constant Temperature

1. The normal temperature. No characteristic of the human mechanism is more remarkable than its constant temperature. Whether we are awake or asleep, by night or by day, at work or at rest, at home or abroad, in summer or in winter, in the tropics or in the polar regions, in subterranean caves or on lofty mountain peaks, the temperature of healthy human beings is always nearly the same. So steady is this temperature that an increase or decrease of two or three degrees gives just cause for anxiety, and a change of seven or eight degrees is looked upon with alarm.

In many modern homes and other buildings constant temperatures are obtained by the use of a *thermostat*, the apparatus of which is visible and easily understood; but no such special apparatus regulates the constant temperature of the human body, and we have rather to seek an explanation in the coördinated activities of organs already familiar, such as muscles, skin, blood vessels, and especially the all-controlling nervous system.

2. Temperature and chemical changes. Every chemical reaction takes place more readily under some external physical conditions than under others, and among these conditions none is more important than temperature. This fact is illustrated in the case of the enzymes. At the freezing point saliva exerts no action upon starch paste; as the temperature rises, the activity of the enzyme increases up

to a certain point and then diminishes more or less rapidly until a temperature is finally reached at which its peculiar chemical properties are destroyed.

3. Temperature and vital activities. When we come to the activities of living cells — activities which, it will be recalled, depend on chemical changes — precisely the same thing holds true, and in so striking a manner as to create a widespread but erroneous impression that this dependence upon temperature is peculiarly characteristic of living things. The one-celled animal, amœba, moves about more actively and digests more food at 20° C. than at 10° C.; bacteria grow more rapidly at ordinary room temperature than near the freezing point; the pitch of the note made by a cricket rises with the temperature, indicating that the movements of the wing covers which produce the sound are being made more rapidly; and in the winter sleep of hibernating animals we have a beautiful example of the decline of vital activities with the fall of external temperature.

Nor are the living cells of the human body exceptions to this rule. The rate of the heart beat varies directly with the temperature of the blood, and the character of the breathing movements is influenced by the same cause; a cooled muscle contracts more slowly, a cooled gland secretes less abundantly. If the temperature of the body itself falls, every vital activity is depressed, and death itself may result from undue cooling.

4. The constant temperature of the body. This depression of nervous, muscular, and glandular activity results, however, only from a fall of the temperature *of the body*, not of that of the surrounding air or other medium. These two things are by no means the same, as may be readily seen from the fact that a thermometer placed in the mouth indicates practically the same temperature of the body on warm and on cold days; even while we are shivering with cold the

thermometer gives about the same reading as when we are enjoying the warmest summer weather. The temperature of the body remains nearly constant, regardless of changes in the temperature of the air around it.

We have only to appeal to experience to see that this is not the way in which lifeless matter generally behaves; a stone, the earth, a piece of iron is warmer on a warm day and colder on a cold day; in general, lifeless things take the temperature of the medium in which they are placed, and this is one of the fundamental principles of physics. Nor do most living things act differently; the temperature of a plant or a tree, of an earthworm, a frog, a turtle, a snake, or a fish, does not differ greatly from that of its surroundings. It is *only birds and mammals* which show this remarkable power of maintaining an approximately constant body temperature notwithstanding a wide range of temperature in the surrounding air. Such animals are known as *warm-blooded*, because they are usually warmer than surrounding objects; those animals which do not thus maintain a constant temperature, on the other hand, are known as *cold-blooded*.[1]

It is clear that the power to maintain a constant body temperature is of the utmost importance in enabling an animal to counteract the varying conditions of climate. Were it not for this power, man would be a hibernating animal; with the coming of winter all his activities would gradually be slowed down and, long before our rivers and ponds had begun to freeze, all business, industrial life, and intellectual life would come to a standstill; it would not be possible for the human race to people every part of the earth — polar, temperate, and tropical.

[1] Cold-blooded animals exposed to a temperature of 99° F. are as warm as warm-blooded animals. The former are so called because they usually feel colder when handled than do warm-blooded animals; but this is merely because the temperature of the air or water in which they live (which is also their temperature) is usually lower than the temperature of warm-blooded animals.

5. The temperature of the body not absolutely constant. The term "constant" as applied to the temperature of warm-blooded animals is not, however, to be taken too literally. No animal has an absolutely constant temperature. In the first place, there are slight variations from time to time under the changing conditions of life. The temperature may be higher by from one to four degrees during muscular activity than during rest; it varies during the day, being highest in the afternoon and lowest in the small hours of the morning; it is often raised half a degree or more by taking food, and marked changes of surrounding temperature may cause a change of one degree or even more in that of the body. These changes between 97.5° and 99.5° F. are of everyday occurrence and are entirely normal; so that when we speak of the temperature of the body being constant we mean that it varies only within narrow limits or that it is constant in comparison with that observed in cold-blooded animals.

6. The temperature of different organs. Nor is this all; some parts of the body have a higher temperature than others. Thus the temperature of the liver and the muscles is said to be very high during activity; that of the blood in the right side of the heart is usually a fraction of a degree higher than that of the blood in the left side. But it is in the skin that we meet with the widest variations from the general average. Everyone knows that on a very cold day the temperature of the skin may be far below 98.6° F.; indeed, the experience of frosted ears or feet shows that at times cutaneous temperature may descend to, or even below, the freezing point itself; and it is very exceptional indeed when the skin temperature is above 92° or 93° F., even on very hot summer days. These variations are due to the fact that the skin is the organ which is immediately exposed to the changing environment and hence peculiarly subject to cooling influences. It is there-

fore customary to distinguish between an outer body zone of variable temperature and the more constant temperature of internal organs.

7. Measurement of the body temperature. The great equalizer of the body temperature is the blood. Blood which has flowed through the skin comes away cooled; that which comes from an organ like the liver or a working muscle, in which active oxidations or other chemical changes have taken place, is heated. In the great veins and in the heart the warmer blood is mixed with the cooler, and an average temperature of the arterial blood results. It is this average temperature of the arterial blood flowing to the organs that is approximately constant.

When this blood flows for a time through an organ which is itself not producing heat and is at the same time protected from loss of heat, the organ ultimately takes on the temperature of the blood; so that by measuring the temperature of such an organ we get the temperature of the blood itself. It is customary to take the temperature in the mouth, the bulb of the thermometer being placed under the tongue and the lips kept closed. Subject to the variations mentioned above, the normal temperature of the mouth is 98.6° F.

8. The feeling of cold or warmth not a true test of the body temperature. It is well at this point to warn the student against confusing the body temperature with sensations of cold or warmth. Just as visual sensations are aroused only by that light which falls upon the sense organ especially adapted to respond to its stimulation, — namely, the eye, — while light falling upon the skin arouses no such sensation, so heat and cold can excite the corresponding sensations only when they act on special end organs adapted to receive these stimuli, and these end organs are found only in the skin, the mouth, and perhaps the nose, pharynx, and upper

esophagus. We are therefore conscious only of the temperature of these organs; we are not and cannot be conscious of the temperature of the blood or of internal organs generally. It is therefore clear that our feelings give us no reliable information as to the temperature of the internal parts of the body. This fact is strikingly illustrated in the case of a "chill," when the internal temperature is almost always really above, and not below, the normal; and the feeling of warmth produced by muscular activity or by warming one's self at a fire merely indicates a higher temperature of the skin, not a higher temperature of internal organs.

Having now learned the more obvious facts about the constant temperature of the body, we have next to inquire by what means this constant temperature is maintained.

9. The production and the loss of heat. We must first remember that *the body produces or liberates heat.* The chemical changes, largely oxidative in character, which are at the basis of the work of its muscles, glands, nerve cells, and so forth, liberate heat just as truly as the burning of coal in the furnace of an engine liberates heat. Heat production is therefore an indispensable result of cellular and organic activity, and it is greatest in those organs, like the muscles and liver, which carry out the most active chemical processes. The body is warm for the same reason that a stove is warm; that is, because heat-producing chemical changes, largely of an oxidative character, are going on within it. In the second place, *the body is always losing heat,* and this in two ways: (1) by the *transfer of heat* by conduction, convection, and radiation[1] to colder objects or to the colder air with which the body is surrounded, and (2) by

[1] Those not familiar with the meaning of the terms "conduction," "convection," and "radiation" will find them explained in section 26 of this chapter (p. 246). In the following discussion we have arbitrarily adopted the term "transfer" to include these three means of loss of heat, in order to distinguish them from the loss of heat by evaporation.

the *evaporation* of water from the surface of the body — especially by the evaporation of the water of perspiration.

Everyone knows in a general way that when a warm body is brought near a colder one, the former becomes colder and the latter warmer; heat is transferred from the warmer body to the colder. In this way the clothing is warmed by contact with the body; also the air in immediate contact with the skin is warmed; and, conversely, the body may be warmed by contact with anything warmer than itself, a hot-water bottle, for example. It is not, however, necessary that two solid bodies be in actual contact in order that heat may pass from one to the other. A stove warms all the objects in a room, although few of them are touching it; and the human body may lose heat to, or gain heat from, objects at a greater or less distance. The heating of the body by the sun, millions of miles away, clearly shows this fact.

The loss of heat by evaporation of water or other liquid from the skin may be readily illustrated by the simple experiment of blowing a gentle current of cool, dry air over the *dry* hand and comparing the cooling thus produced with that which results from blowing a similar current against the *moistened* hand. In the latter case the cooling will be much greater than in the former. Ether, and other liquids which evaporate more rapidly than water, can lower the temperature even more.

10. The heat account of the body. The body is therefore constantly receiving and constantly giving out heat, just as a bank is constantly receiving and paying out cash. In the bank a cash account is kept, on one side of which is entered the cash received and on the other the cash paid out. The difference between the two sides, known in business as the *balance* of the account, shows how much cash is on hand at the time of taking the balance. Should the cash unduly accumulate, efforts are made to keep down the balance by increasing loans; should the cash on hand fall below a

desired level, active efforts to encourage loans are lessened and the normal desired balance is restored; finally, should there be an unusual demand for cash at the window of the paying teller, — for example, a "run on the bank," — the bank will borrow from other banks and in this way keep income and outgo of cash approximately equal.

In what follows the student will learn that this is precisely what the body is doing with regard to heat. We may, indeed, imagine a heat account of the body, the two sides of which would be as follows:

DEBIT (Heat received)	CREDIT (Output of heat)
1. Heat produced within the body.	1. Heat transferred to surrounding objects colder than the body (by conduction, convection, and radiation).
2. Heat transferred to the body from warmer objects outside (by conduction, convection, and radiation).	2. Heat lost in evaporating water of perspiration.

The balance of this heat account at any one time is the amount of heat in the body, and this determines the temperature of the body. When the output of heat exactly equals the heat received, the account balances; that is to say, the temperature is constant. A constant temperature, therefore, means that the two sides of the heat account are being kept equal to each other.

11. Transfer of heat dependent upon the nature of the vehicle of transfer. The rate at which heat may be transferred depends upon the nature of the substance through which the transfer occurs and which we may speak of as the vehicle of transfer. We cannot go minutely into the factors here concerned, but would call attention to the following points, which will be readily verified from experience:

1. *A gas is in general a poorer vehicle of heat transfer than a liquid or a solid.* We make use of this fact in the manu-

facture of fabrics for our winter clothing, for these fabrics are warm according to the quantity of air within their meshes. A woolen garment is warmer than a cotton garment because it contains within the fabric so large a quantity of air, which is a poor conductor; or, of two woolen garments of the same thickness, one being rather loosely and the other tightly woven, the loosely woven garment will be much the warmer because so large a proportion of its thickness consists of the poorly conducting air rather than of the more rapidly conducting solid woolen fibers (see page 526). Or, again, air of 70° F. is very comfortable; it feels neither cold nor warm to the skin; but water of 70° F. feels distinctly cool. This is because heat is conducted away from the skin more rapidly by water than by air. For this reason we may feel chilly when our clothing has become drenched with rain.

2. *Moist air is a better vehicle of heat transfer than dry air.* This becomes obvious when one is exposed to damp air at a temperature of less than 70° F., and the familiar difference between dry and damp winds in winter illustrates the same fact, for a damp wind at 50° F. chills the skin more than a dry wind at 40° F. The student is cautioned, however, against supposing that dampness always favors the output of heat from the body; it favors only one method of heat output, namely, the *transfer* of heat. On the other hand, dampness hinders the output of heat by evaporation. Hence at those temperatures (above 80°) where the output is chiefly by evaporation, a damp atmosphere is hot and muggy; where the output is chiefly by heat transfer (below 70°), a damp atmosphere is chilly.

12. The evaporation and not the secretion of perspiration cools the body. The student should understand clearly that it is the evaporation of the perspiration, not the secretion of it, which abstracts heat from the body. Perspiration may be

secreted in large quantities, but if it does not evaporate, — as happens on a very muggy day, when the atmosphere already contains about as much aqueous vapor as it can hold, — it takes little or no heat from the skin. Nor is the efficiency of the perspiration as a cooling agent measured by the amount of visible or "sensible" perspiration, for this is only the perspiration which has not evaporated; the true measure of the cooling effect would be the perspiration which has evaporated and of which we are not conscious.

It is important to note that the evaporation of perspiration (or of water from the lungs and air passages) is the only means of cooling the body when objects around it are warmer than the body itself. In this case the agents of heat transfer only add heat to the body, but even their combined action may often be overcome by an abundant evaporation of perspiration. Men have remained for some time in rooms the temperature of which was as high as 260° F., or forty-eight degrees above the boiling point of water, without any marked elevation of the body temperature and without severe discomfort, the temperature of the body being kept down solely by the evaporation of perspiration from the skin. In order to make this means of cooling possible, it is absolutely essential that the air be dry and capable of taking up moisture. No one can survive long at such temperatures in moist air.

13. The effects of stagnant and of moving air; the air blanket. On a perfectly still day the layer of air about the body becomes warmed by the skin and, so long as it is not removed, forms an air blanket which goes far to keep the skin warm, for air is a poor conductor of heat. As soon, however, as a breeze springs up, convection comes into play and the skin is cooled more rapidly. In stagnant air, moreover, the evaporation of the perspiration tends to saturate this air blanket with water vapor, so that further evapora-

tion is rendered difficult. Accordingly, when perspiration is not being secreted, moving air cools the body by increasing convection; and when the skin is moist it cools the body both by increasing convection and by facilitating the evaporation of perspiration. The breeze which in winter is an unwholesome draft, in summer is often absolutely essential to working power as well as to bodily comfort, for without it we are clothed in this air blanket which becomes heated to our temperature and prevents our getting rid of more heat.

II. The Regulation of the Body Temperature

14. How the balance of the heat account may be disturbed. Events both within the body and in its immediate surroundings tend to change the balance of the heat account, that is, to upset the equilibrium previously existing between heat loss and heat production. The most important of these events are (1) muscular activity and the digestion of food within, and (2) changes of weather conditions without. Let us consider how each of these acts.

1. *Muscular activity*, by producing more heat within the body, would tend to increase the heat balance; and, unless measures were taken at the same time to increase heat output, the temperature of the body would rise. Muscular activity may double or even treble the heat produced. The *digestion of a meal* similarly liberates heat within the body and so tends to raise its temperature, but the heat produced in this case is far less in amount than that produced during muscular activity.

2. *Changes of weather conditions* act by changing the ease with which heat is lost; and, remembering that heat is lost in two ways, — by transfer to colder surroundings and by evaporation of perspiration, — we must inquire how various weather conditions influence each of these

agents of heat output. The three main weather conditions are the *temperature*, *movement*, and *moisture* of the air. The following tabular form will aid in understanding the relation of each of these conditions to the heat output of the body.

I. TEMPERATURE OF AIR

A. Influence on Heat Transfer

Heat is transferred more rapidly to colder surroundings than to surroundings which are near the temperature of the body.

B. Influence on Evaporation

The warmer the air, the greater the capacity and rapidity of its taking up water vapor. This facilitates the evaporation of perspiration on a warm day, when this is most needed to cool the body.

II. MOVEMENT OF AIR

A. Influence on Heat Transfer

Movement of air increases heat transfer to the atmosphere by replacing the air blanket of warmed air with colder air, to which heat is transferred more rapidly.

B. Influence on Evaporation

When perspiration is evaporating into stagnant air in contact with the skin, this air becomes more nearly saturated with water vapor, and its power of absorbing water vapor is lessened. By replacing the air blanket of muggy air with dry air, the output of heat by evaporation is greatly favored.

III. HUMIDITY OF THE ATMOSPHERE

A. Influence on Heat Transfer

Humidity increases the rate of transfer of heat, as explained on page 231. This is of little importance on warm days, because little heat is then transferred either by dry or by moist air. On cooler days it is of great importance.

B. Influence on Evaporation

Humidity diminishes the output of heat by evaporation, because the water vapor which the atmosphere can take up is limited and a humid atmosphere is one already largely saturated. This influence of humidity is of no consequence unless perspiration is being secreted, but it is a very important matter on warm days.

15. How the heat balance, when disturbed, is restored by the body. In these ways changes in the activities of daily life and changes of weather tend to change the heat balance of the body — that is to say, they tend to change the temperature of the body. And they would do this, did not the body possess the power, within certain limits, of changing both its rate of heat loss and its rate of heat production.

The rate of heat loss may be changed in two ways: (1) by changing the quantity of blood flowing through the skin. Obviously the more the warmed blood is kept within the internal organs, the smaller will be the amount of heat transferred from the surface of the body to surrounding objects. This explains the reason for the reactions of the circulation to changes of surrounding temperature. The entire vasomotor mechanism with its vasoconstrictor and vasodilator nerves thus forms part of the mechanism of temperature regulation. The rate of heat loss may also be changed (2) by producing a secretion of perspiration. The temperature-regulating action of this secretion becomes effective at about 68° or 70° F. in the body at rest and increases as the external temperature rises. The sweat glands are thrown into action by nervous impulses. Hence the nervous system, through its nerves to the arterioles and the sweat glands, controls the output of heat from the body.

The nervous system also controls the rate of heat production, for this is changed by increasing or diminishing the activity of the skeletal muscles. We are likely to be more active on cold than on warm days, and this apart from any conscious adjustment of muscular activity to the temperature needs of the body. We shall return to several interesting features of this part of our subject in later paragraphs.

16. Reactions of the lightly clad body at rest to changes of external temperature. Having learned the more important principles concerned in maintaining the constant heat bal-

ance, let us now observe the actual behavior of the body as the external temperature changes, assuming that the air remains of moderate humidity and that there is little or no wind.[1] To do this let us suppose that the body at rest and lightly clad is exposed, to begin with, to a temperature of 90° F. At this point but little heat is transferred by conduction, convection, and radiation from the skin to surrounding objects, since both are so nearly of the same temperature. Hence the main reliance for getting rid of the heat constantly being produced is upon the evaporation of perspiration, which is abundantly secreted; the cutaneous arterioles are also widely dilated. Let us now suppose the day becomes cooler and the temperature falls to 80° F. Heat production remains unchanged; but more heat is now transferred to the cooler surrounding objects, and less is lost by evaporation because less perspiration is secreted. As the external temperature falls further, still more heat is transferred to colder objects and correspondingly less is lost by evaporation of the perspiration until, somewhere about 68° to 70° F., exactly the same amount of heat is lost by conduction, convection, and radiation as is produced. *At this point the secretion of the perspiration ceases.*

Thus far the difficulty in maintaining a constant temperature has been that of getting rid of heat under atmospheric conditions which are unfavorable for the ready conduction, convection, and radiation of heat from the skin. Blood is brought in large quantities to the skin and correspondingly drawn away from the internal organs, and the evaporation of perspiration becomes increasingly important as the external temperature rises from 70° to 90° and 100° F. *The organism is striving against a rise of its body temperature.*

About 68° or 70° F., however, the situation changes; for, as the external temperature continues to fall, heat begins to

[1] Consult Fig. 91 when reading this section.

be transferred to surrounding objects more rapidly than it is produced. The temperature of the body would fall if no means were taken to prevent that result. Even during the fall from 90° to 70° the cutaneous arterioles, widely dilated at the higher temperature, have been gradually increasing

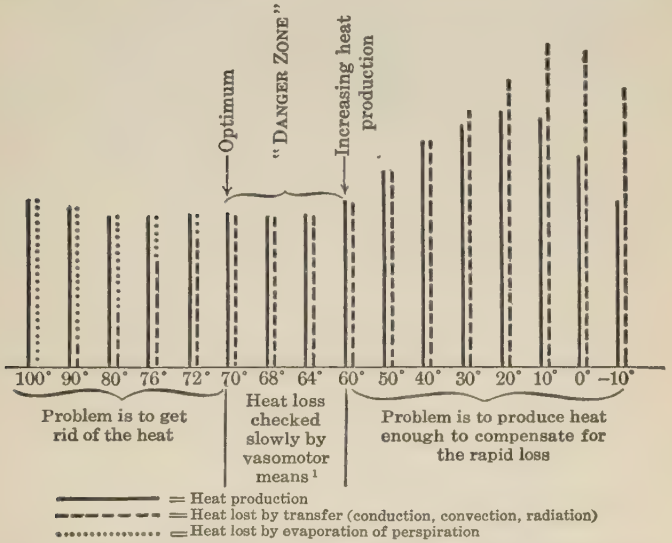

Optimum
"Danger Zone"
Increasing heat production
100° 90° 80° 76° 72° 70° 68° 64° 60° 50° 40° 30° 20° 10° 0° −10°
Problem is to get rid of the heat
Heat loss checked slowly by vasomotor means[1]
Problem is to produce heat enough to compensate for the rapid loss
= Heat production
= Heat lost by transfer (conduction, convection, radiation)
= Heat lost by evaporation of perspiration

FIG. 91. Production and output of heat at different temperatures

their tone and so sending diminishing quantities of blood through the skin. *Below 68° to 70° this tone rapidly increases*; the veins are no longer conspicuous on the hand and arm; if the blood is forced out of a portion of the skin by gentle compression with the finger, the color returns slowly, indicating considerable constriction of the cutaneous arterioles.

[1] Vasomotor reactions are those affecting the size of the blood vessels, either dilating or constricting them. They may be produced (1) by impulses from the brain, (2) by reflexes from the skin and other organs, (3) by changes in the temperature of the blood, and (4) by the presence of hormones in the blood stream (p. 194).

At the same time the arterioles of the internal organs are dilating (see page 179) so that the liver, the kidneys, and the mucous membranes of the alimentary canal and of the air passages contain an increasing quantity of blood. *The body is now striving against a fall of its internal temperature by driving the blood from the skin back upon the internal organs.*

By the time the temperature has fallen to 60° F., or thereabouts, the cutaneous arterioles have contracted to their utmost, the blood flow through the skin has nearly ceased, and the organism has no means at command by which to restrict the further output of heat. If in this emergency heat production were to remain constant while external temperature continued to fall, the temperature of the body would be lowered, for the transfer of heat would not only continue but increase. That it is not usually lowered is due solely to the fact that more heat is then produced within the body; the oxidation (and hence heat production) which have remained fairly constant in amount between 90° and 65° F. now increase to compensate the inevitable loss, and continue to increase as the atmospheric temperature continues to fall. *The body is now striving against the effects of a rapid and inevitable loss of heat, by producing more heat*, and continues to do so until somewhere near the freezing point (32° F.), when it can no longer produce enough heat to balance the loss; the temperature of the body then falls and the man ultimately freezes to death.[1]

Briefly, then, at an external temperature somewhere between 65° and 70° F, heat production exactly equals heat transfer, and it is not necessary that the body make any special effort to get rid of heat or to compensate for heat loss. *The blood is properly distributed between the skin and the internal organs, and there is no excess in either.* This we may call the *ideal* or *optimum* temperature for the given conditions.

[1] In all this it must be remembered that the body is still lightly clad and at rest.

Above this point measures must be taken to provide for an adequate heat output by sending a larger quantity of blood to the skin and by the secretion of perspiration; below this point measures of the opposite kind must be taken to check heat loss, or even to increase heat production.

17. Changes of the optimum temperature with high humidity, with wind, and with muscular activity. High humidity, facilitating the transfer of heat from the body, raises the optimum temperature a few degrees; a room is comfortable

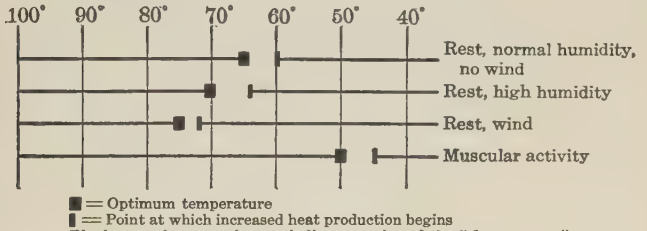

100° 90° 80° 70° 60° 50° 40°
Rest, normal humidity, no wind
Rest, high humidity
Rest, wind
Muscular activity
■ = Optimum temperature
▮ = Point at which increased heat production begins
Blank space between the two indicates region of the "danger zone"

FIG. 92. Variations in the optimum temperature

at 65° F. when the air is dry; it is too cool when the air is moist. Wind may raise the optimum temperature still more, and for the same reason; it may be safe to sit in a breeze at 75° when it is decidedly unsafe to do so at 65° or 70°.

Muscular activity, on the other hand, because of the production of larger quantities of heat, lowers the optimum temperature, for at the lower temperature the agencies of heat transfer can get rid of the excess of heat without a large flow of blood to the skin and without inducing perspiration.

In all cases, — rest or muscular activity, high or low humidity, wind or calm, — wherever the point of optimum external temperature may be, we always find above this point the region of active measures for heat dissipation, and below it the region of active heat production. This is graphically shown in Fig. 92.

18. The "danger zone" of atmospheric temperature. We have seen that, as the weather cools from 70° to 60° F., the main agency employed for temperature regulation is the diminution of the flow of blood through the skin, with its compensating increase of *the flow of blood within the internal organs*, thereby retaining as far as possible the heat within the body. This threatens serious congestion and other unhealthful conditions, which we shall consider at length in our study of hygiene (see Chapter XXI). It is because the temperature of a room may fall from 66° to 60° so gradually that we do not notice it until the internal damage is done, whereas it could not fall to 50° or 40° without our noticing it and correcting the trouble, that more colds are taken in the former case than in the latter. In other words, as the temperature goes below 65° the body seems at first to rely wholly on the vascular mechanism of temperature regulation, and does not begin to produce more heat until this resource has been utilized not only to its utmost, but even to an extent inconsistent with health. The "danger zone" temperature may then be defined as beginning a degree or two below the ideal or optimum temperature and extending about five degrees below this point. Like the optimum temperature, its exact position varies with atmospheric conditions and with the amount of muscular activity.

19. The influence of clothing. In the discussion above we have assumed that the clothing has not been changed with the change of external temperature and moisture. Clothing, however, may modify greatly the figures given above, for it interferes with the loss of heat from the skin, and the obvious effect of increasing the clothing is to lower the optimum temperature and the region of dangerous temperature. By changes of clothing, by muscular activity, and by the use of fans or furnaces, man has it in his power to supplement the unconscious reflex adjustments, which we have thus far

been studying, by a conscious adaptation to changing conditions of climate or weather. The hygienic use of clothing will be discussed in Chapter XXVI.

20. Temperature regulation and muscular activity. The reactions by which the body maintains its constant temperature during muscular activity are familiar to everyone, and it is only necessary to sum them up and to point out some practical applications. During exercise the cutaneous arterioles are dilated (while those of the internal organs are constricted) and perspiration is secreted. These are the same reactions which are noticed when the body is exposed to external warmth, and their purpose is the same in both cases — to facilitate the escape of heat. But in the one case they are made necessary by the fact that climatic conditions interfere with the output of heat, in the other by the fact that more heat is being produced and hence more must be got rid of.

Seldom indeed is so severe a strain imposed upon the mechanism of heat dissipation as during vigorous muscular exertion, and especially when the external conditions are not favorable for the output of heat. Caution is then urgently indicated lest we make the strain too great. It is a practical point to remember in this connection that some forms of muscular exertion introduce conditions for getting rid of the surplus heat much more readily than others; this is especially true of those which involve movement of the body as a whole. Bicycle or horseback riding, by creating a breeze, renders the cooling of the body a much easier matter than does sawing wood, or swinging Indian clubs, or gymnastic work in general; again, a particular form of exercise may be safe on a dry day, when the perspiration can evaporate readily, while it would be decidedly inadvisable on a muggy day, even though the temperature were somewhat lower. Indeed, by this time the student must have learned that

the thermometer alone is no safe indicator of the difficulty of heat elimination in warm weather.

21. Relations of climatic conditions to mental activity and sleep. During mental activity the brain requires an increased supply of blood, and this is obtained partly by diminishing the supply to the skin (constriction of cutaneous arterioles); during sleep, on the other hand, the supply to the brain is diminished, and this is ordinarily effected by dilating these arterioles (see page 182). Mental work is difficult on very warm days, partly because it is difficult to bring about cutaneous constriction; and it is especially difficult on warm, muggy days, since the maintenance of the constant temperature then requires an excessive cutaneous dilation, and the brain is quite unable to command its needed supply of blood.

It is also clear that since the cutaneous arterioles should dilate during sleep, and since they cannot readily do this when the skin is exposed to cold, to "sleep warm" is good advice, based on sound physiological principles.

22. Digestion and the maintenance of the constant temperature. During digestion, and especially during its earlier stages, when secretion is at its maximum, a large supply of blood is needed in the stomach, the pancreas, and the intestines. This cannot readily be secured when blood is being sent in large quantities to the skin in order to cool the body. We have seen all along that the two great vascular areas, the skin and the digestive organs, are more or less antagonistic or compensating in their vasomotor reactions. When the blood is present in large quantities in the skin, it is present in smaller quantities in the stomach, the intestines, the pancreas, and the liver; and, vice versa, these organs can best obtain an adequate supply of blood when the demands of the skin are not excessive. Consequently digestion is more difficult in warm than in cold

weather, and we should then eat less at a time, even if we have to eat somewhat more frequently.

During the digestion of a meal the chemical activities of secretion, the peristaltic muscular movements, and so forth, somewhat increase heat production in the body; and this addition, though not great, is at times great enough to make us feel distinctly warmer. When one is *slightly* chilly, for example, he often feels warmer after eating something, even though the meal be cold; and on a very warm, muggy day, when the flow of blood through the skin is already excessive and its temperature unduly high, the digestion of a meal often adds to the discomfort, because the larger production of heat leads to further dilation of the cutaneous arterioles.

23. The mechanisms concerned in temperature regulation. The preceding pages have shown us that temperature regulation depends chiefly on three physiological mechanisms: (1) the vasomotor system, which controls the distribution of blood and hence of heat between the skin and the internal organs; (2) the sweat glands, which regulate the loss of heat by evaporation from the skin; and (3) the skeletal muscles, which are the main site for the production of heat. The heating of the skin stimulates afferent nerves which reflexly dilate the cutaneous arterioles and also simultaneously constrict those of the internal organs. This reflex, then, is dependent on the temperature of the skin; anything which heats the skin causes a reflex dilation of its arterioles and lessens the supply of blood to the internal organs.

The secretion of perspiration also is under the control of the nervous system. The sweat glands, like the salivary glands, receive nerves (Fig. 93) and secrete only in response to their stimulation. When the nerves going to the sweat glands of any region are injured, exposure of these glands to external warmth produces no perspiration; stimulation of their nerves, however, produces a copious secretion.

24. The skeletal muscles the main organs in the regulation of heat production. The third mechanism of heat regulation is that whereby the amount of heat produced is increased as it is needed. The main organs here concerned are the skeletal muscles. As the afferent impulses started in the skin by the stimulation of cold become stronger, they

FIG. 93. Diagram of the cutaneous reflexes for temperature regulation
Showing the epidermis, blood vessels of the dermis, a sweat gland, and the nervous mechanism governing blood vessels and sweat glands

ultimately stimulate reflexly the skeletal muscles to contraction, and so to the production of heat. This contraction does not necessarily produce motion, because antagonistic muscles are stimulated equally; but in another way we are often conscious of this increased muscular action. Everyone knows the difference between the "bracing" effects of a cool or cold day and the "relaxed," "lazy" feeling on a warm day; and this is largely traceable to the sensations which come from the contracting muscles in the former case and to the absence of such sensations from the inactive

muscles in the latter. To put it in another way, cold increases the *tone of the skeletal muscles* (see page 193). A skeletal muscle on a cold day is never completely relaxed; like the unstriped muscles of the arteries, it is in a condition somewhere between extreme contraction and extreme relaxation.

This muscular reflex also betrays itself in *shivering*. Ordinarily the reflex contraction consists of an even, steady tone, but at times it becomes more or less incoördinated, and shivering results.

25. The regulation of the body temperature a function of the nervous system. We may close this brief account of the thermal phenomena of the body by recalling to the attention of the student what must now be obvious, namely, that a constant temperature is maintained by the coördinating action of very many nervous reflexes. The action of the vasomotor nerves in the skin and in the internal organs, of the nerves controlling the sweat glands, and of the motor nerves in the skeletal muscles must all be so adjusted with regard to one another that exactly the right balance is preserved amid all the variations of heat production and of climatic conditions which affect heat loss. Success in this adjustment depends upon the skill with which the coördinating nervous system does its part. With the single exception of muscular exertion, no condition of life makes such far-reaching or such imperious demands upon the system as a whole as does the maintenance of the proper internal temperature. Mental activity and the efficiency of digestion are examples we have already studied — and more could easily be cited — of functions which, important as they are, are subordinated, even sacrificed, to prevent a marked rise or fall in the temperature of the blood.

We know already how the nervous system intervenes in every activity of our lives, and how the well-being of the body as a whole depends upon the adjustments which it

brings about. To such an extent is it, as a whole, adapted to maintain the temperature constant, that its failure to do this, as shown by the presence of fever or by subnormal temperature, becomes one of the most important indications that something is seriously wrong and that a physician should be called. It is for these reasons that, when the nervous system is no longer able to exercise firm control over the body temperature, the physician's orders usually are to "go to bed and keep perfectly quiet." A person who refuses to heed the plain warning which his temperature holds out has nothing but his own foolishness to blame if he suffers serious consequences.

26. Definitions. Those not familiar with the exact meaning of the terms "conduction," "convection," and "radiation" will find the following helpful:

Conduction. Whenever heat is transferred directly from one mass of matter to another with which it is in *contact*, such transfer is known as conduction. A good example is the heating of a poker in a fire; the heat of burning coal is communicated directly to the outer particles of iron and then from one particle of iron to another. The particles of iron do not move up and down the length of the poker; each one simply passes on to the next one some of the heat it has received, and finally those of the handle communicate their heat to the hand. All transfer of heat *along solid objects*, or from one mass of matter to another with which it is in immediate contact, is by means of conduction.

Solids and liquids are much better conductors of heat than gases, and air when perfectly still is one of the poorest conductors of heat with which we have to deal. It is a familiar fact that the skin is chilled much more rapidly by water than by air of the same temperature (why?); and we shall learn in hygiene that warm fabrics owe their warmth mainly to the amount of poor-conducting air stagnant within their meshes.

Convection. When a warm body is surrounded by a fluid such as water or air, heat is similarly conducted to the adjacent layer of water or air, which thus becomes warmer; but, unlike the case of the solid, this heated layer now moves off, carrying its heat with it to other parts of the gas or liquid, and so communicating it to other matter

with which it subsequently comes in contact. This method of heat transfer is known as convection, which, it will be seen, depends at bottom upon conduction, but which is at the same time modified by the *movement* of a heated gas or liquid. So long as the air around us is at rest, it does not remove heat readily from the skin, since air is a poor conductor. Air in motion, on the other hand (as when it is fanned), cools the skin more rapidly, because each part of the air, as it is heated, is moved away and replaced by colder air. In this case the air cools the skin by convection (Latin *con*, "with"; *vehere*, "to carry").

The transfer of heat from the internal heat-producing organs to the skin affords an excellent example of the difference between conduction and convection, for some of this heat passes by direct *conduction* through the subcutaneous tissue to the overlying skin, while some of it is carried to the surface by *convection* in the blood stream. When the cutaneous arterioles are dilated, convection is an important means of heat transfer to the surface; when, in the reverse case, the cutaneous arterioles are constricted to their utmost, convection becomes relatively unimportant and direct conduction remains as the chief means of heat transfer to the skin. Moreover, when the subcutaneous tissue contains large amounts of fat, it is a poor conductor of heat, and for this reason fat people when sitting still on cold days often *feel* colder than lean people do.

Radiation. Heat is thus removed from the skin by conduction, and at times to an even greater extent by convection. But there is still a third method of heat loss, known as radiation, by which heat can be transferred across a space in which there is no solid, liquid, or gas, and in which conduction and convection are consequently impossible. The most familiar and striking example of radiation is the transfer of heat from the sun to the earth, since there is no atmosphere in the greater part of the more than ninety million miles of space which separate us from that intensely heated body.

Any detailed consideration of radiation belongs to the domain of physics rather than physiology and would be out of place here. It is enough for our present purposes to understand that, whether a solid body be in air, or in a transparent liquid, or even in a vacuum, it transfers or loses heat by direct *radiation* to colder objects about it. From an open fire heat may be transferred by *conduction* to andirons or walls in direct contact with it; also by *convection* through heated air currents to the chimney top; and, finally, by *radiation* to persons standing in front of it. In the latter case the heating is chiefly by radiation, since there is no contact with the fire, and such air currents as exist are mostly

composed of cool air sucked toward and into the chimney by its draft. It is for these reasons that open fires are said to "roast people in front and freeze them behind." In the same way the human body, if warmer than its surroundings, may lose heat by conduction, convection, and radiation to cooler objects in the vicinity.

The practical importance of these facts is seldom realized. It often happens that the air in contact with the skin is of the proper room temperature; and yet, if one is sitting too near a cold wall or window, enough heat may be lost by *radiation* from the skin to the cold wall, through the warm air, to chill the skin materially, causing a loss of heat and a consequent "cold."

Laws of conduction, convection, and radiation. For our purposes the most important factors which determine the loss of heat are (1) the difference in the temperature of the two objects and (2) the distance between them.

In general, the greater the *difference of temperature,* the more heat will be lost from the warmer to the colder object; thus the skin loses heat rapidly by these means when surrounding objects are at 0° F., but only slowly when they are at 90°. It is also clear that as soon as the temperature of surrounding objects and of the atmosphere is as high as that of the body (98.6° F.), no further heat can be lost by conduction and radiation; and that above 98.6° F. heat is conducted and radiated *to* the body, not *from* it.

Furthermore, the greater the *distance* of the colder object from the body, the less heat will the body lose to it. Here heat loss takes place inversely as the square of the distance; that is, when we are twice as far away from a cold (closed) window or a cold wall, we lose only one fourth as much heat to it; if we are three times as far away, we lose only one ninth as much, and so on. Consequently, we rapidly diminish transfer of heat from our bodies by sitting farther away from the cool walls of a room; and it is important to have our living rooms large enough to make it unnecessary to sit near the windows or near a cold outer wall in very cold weather.

CHAPTER XIII

NUTRITION

The various nutrients, or essential constituents of foods, were studied in the chapter on Foods and Digestion. These, it will be recalled, are proteins, fats, carbohydrates, inorganic salts, vitamins, and water. Our dietary must be sufficient in variety and ample in quantity to meet the following fundamental needs of the body: (1) power for the activities of the muscles, heart, and so forth; (2) heat for maintaining the body temperature; (3) growth and repair of the cells; (4) secretions, internal and external, and other self-manufactured compounds needed in the activities of the body; and (5) reserve material to be stored up for emergencies. Since the term "fuel" is employed in industry to designate substances which yield heat and power, the first two of the functions of foods may be referred to as their "fuel value." The same food constituents supply both of these needs; hence we may consider this aspect of nutrition first.

I. The Sources of Power and Heat for the Human Mechanism

1. The fuel value of food. In any locomotive engine the same amount of a given fuel will enable the engine to pull a train of the same weight for the same distance over the same track, provided, of course, the engine itself, the bearings of the wheels, and all other conditions are the same. When a ton of coal is put into the tender, it is with the

expectation that it will move the train a certain distance. Thus there is a definite relation between the fuel burned and the work done. Every engineer knows also that the same weight of different fuels will carry the train different distances; a ton of wood, of bituminous coal, and of anthracite coal have different *fuel values.*

The same weight of a given fuel when burned will always yield exactly the same amount of heat, as is proved by burning the fuel under conditions which enable us to measure the heat given off. The simplest means of doing this is perhaps with the *ice calorimeter* — a metal box within which the fuel is burned, the box being everywhere surrounded by a thick layer of ice. The heat produced in burning the fuel is measured by the amount of ice melted.

In this way we may find the relative amounts of work which can be done with two different fuels, for it has been discovered by actual experiment that if one kind of fuel produces twice as much heat as another, it will also do twice as much work.

Now food is the fuel for the muscular work of the body and also for the production of heat. Consequently, if we determine how much heat is produced when a certain amount of protein, or fat, or carbohydrate is burned in a calorimeter, we know how much work it *may* do in the body; or at least we know that it can do *no more* than the amount indicated by the calorimetric experiment.

2. Units of heat and work. In order to measure we must have units of measurement. Common units of length are the inch or centimeter; units of area are the square yard, square meter, or acre; units of volume, the quart or liter; units of weight, the pound or kilogram. We express the results of measurements by saying that a thing is so many inches long or of so many pounds weight. What are the units of heat and of work?

Like all units, these are arbitrarily chosen. *The unit of heat*, known as the Calorie[1] and abbreviated Cal., is the amount of heat necessary to raise the temperature of one kilogram of water one degree centigrade (or, to be more exact, from 15° to 16° C.). The *unit of work* is the amount of work done in lifting a kilogram (2.2 lb.) to the height of one meter (39.37 in.) from the surface of the earth, against the attraction of gravitation. This is known as the *kilogrammeter*. Thus, when a man weighing sixty kilograms goes up a flight of stairs ten meters high, his muscles do 600 kilogrammeters of work.[2]

Finally, it has been found that the same fuel which when burned will liberate one Calorie of heat will supply the power to do 423.985 kilogrammeters of work. By this we mean that not more than 423.985 kilogrammeters of work can be obtained from it. Not every engine is so perfectly constructed as to get from a certain fuel its full working capacity; indeed, most engines transform only a small fraction of the power of their fuel into work, the rest being dissipated as heat (in the smoke, or by radiation, conduction, and convection from the furnace, boiler, and so forth) or as friction due to the rubbing of the various parts of the engine against one another. But by the method above outlined it is possible to find the maximum amount of work which can be obtained from a given weight of fuel.

Applying the same methods to food, we find that

1 gram of dried *protein* yields 4.1 Calories.
1 gram of dried *carbohydrate* yields 4.1 Calories.
1 gram of *fat* yields 9.3 Calories.

These figures are known as the *fuel values* of proteins, carbohydrates, and fats, as oxidized in the body.

[1] This is the unit employed in the study of nutrition. It should be written with a capital C to distinguish it from a much smaller unit of the same name.

[2] Work may also be expressed in foot pounds. (How many foot pounds equal one kilogrammeter?)

But the total possible power which may be obtained by actually burning a certain substance under the most favorable conditions is one thing, and the amount of power which the muscles may obtain from it is quite another. When coal is burned in an engine it produces energy, but the human body would get no energy for its muscular work from eating coal. Hence we have now to inquire from what nutrients the muscles get their energy for work and from what nutrients the body derives its heat.

3. The supply of power for muscular work. Few questions in physiology have been more thoroughly investigated than this. In the first half of the nineteenth century many investigators, impressed with the fact that the muscle fiber yields, on chemical analysis, large quantities of protein and only traces of carbohydrates and fats, believed that the energy for muscular contraction comes entirely from the breaking-down of the protein of the muscle itself. If this were true, it would necessarily follow that protein is the proper food to yield the energy for muscular contraction, while fats and carbohydrates would simply be oxidized to give heat.

This view was disproved by the following epoch-making physiological experiment: Two observers determined for three successive days the amount of nitrogen excreted by themselves; since almost all this nitrogen comes from protein, this gave the amount of protein consumed by the body. On the first and third days no vigorous muscular work was done; on the second day they climbed a mountain 1956 meters (6415 ft.) high. As one man weighed 66 kilograms and the other 76 kilograms, the work done in lifting the body to the top of the mountain in the two cases was 129,096 and 148,656 kilogrammeters respectively. The protein which was oxidized in this time could in the two cases have yielded power for only 63,378 and 61,280 kilogram-

meters of work. In other words, the protein did not begin to yield sufficient power for the muscular work done in lifting the body to the top of the mountain; something else than protein must have been oxidized for the purpose, and that something must evidently have been carbohydrate or fat, or both.

Again, it was noticed that there was no increase of protein disintegration on the day of work; this remained practically unaffected by muscular contraction. Numerous other experiments made since that time have shown the same thing. Muscular exercise does not *necessarily* increase protein disintegration, and the power for it can be obtained from fats and carbohydrates.

In the experiment above referred to no determinations were made of the excretion of carbon dioxide. Since then numerous experiments have been made in which, on an abundant mixed diet, both the nitrogen and the carbon of the excretions were accurately determined. These have shown that *while muscular exercise does not necessarily increase protein disintegration, it invariably increases the production of carbon dioxide.* If the carbon of the carbon dioxide came from protein, it would be accompanied by increased excretion of nitrogen derived from the broken-down protein. The fact that it is not so accompanied can only mean that it came from the oxidation of something which did not contain nitrogen, that is, from fat or carbohydrate, or both.

But while muscular work does not necessarily or even usually increase protein decomposition to an appreciable extent, and while power for the same purpose may be derived largely, if not entirely, from carbohydrates and fats, it has been shown conclusively that under certain conditions this power may come entirely from protein. In one experiment a large and very lean dog was fed for several weeks on an abundant diet of lean meat, containing practically no carbo-

hydrate or fat; during this time the dog did large amounts of work in a treadmill and in other ways; and since it was found that this work could be done for weeks at a time on the meat diet, we conclude that the protein must have been the sole source of power for the work; it must also have served as the source of heat production, for the normal temperature of the animal was maintained.

4. Summary of considerations on the supply of power for work. These and other experiments show (1) that the animal body can get its energy for mechanical work and for the production of heat from protein, or from carbohydrate, or from fat; (2) that when the animal is on an abundant mixed diet, even vigorous muscular work does not usually increase the oxidation of protein,[1] but does enormously increase that of carbohydrates and fats. The probable meaning of this is to be sought in the fact that protein decomposition depends primarily, not on muscular work, but, as we shall see later, on the amount of protein eaten; while the oxidation of fats and carbohydrates depends almost entirely on the demands of the body for energy and is largely independent of the amount of these foods eaten.

5. The supply of energy for heat production; "heating" foods. The supply of energy for heat production may be derived from two sources, as follows: (1) the chemical changes accompanying muscular activity and (2) the chemical changes accompanying the digestion and absorption of food.

1. In studying the phenomenon of heat production in the body, we learned that when the body needs to produce more heat in order to maintain its normal temperature, this heat is supplied chiefly by greater chemical activity in the skeletal muscles (p. 244). The contraction or tone of the muscles increases in response to stimuli from the same motor nerves

[1] Under the abnormal conditions of excessive muscular work (for example, six-day walking matches or bicycle races) the protein oxidation is often increased.

which stimulate them to activity when they do external mechanical work. The production of heat is nicely adjusted to the needs of the body.

2. We have all perhaps experienced the feeling of warmth and protection against cold which is afforded us by eating even a cold lunch; also we have all perhaps heard it said that certain food materials are desirable in winter but undesirable in summer because of their heating effects. Recent investigations have shown that these experiences and sayings have a scientific basis, for it has been found that the heat produced by the resting body may be increased (1) 10 per cent by eating an ordinary meal of mixed foods, (2) 30 per cent by eating an equivalent quantity of protein, but (3) only 3 per cent by carbohydrate exclusively, and still less by fat. This production of heat continues only during the absorption of the products of digestion into the tissues; and it is spoken of as the *specific dynamic action* of the foodstuffs. It has been shown that the specific dynamic action of protein exceeds many fold that of the other nutrients. This accounts for the heating properties of the proteins, and also furnishes a physiological explanation for the fact that it is advisable to avoid a meat diet in hot weather.

6. The daily requirement of the body for power and heat. How many Calories must be furnished to the body daily for the maintenance of its activity and temperature? This question has been studied by several methods, but we must content ourselves with a statement of some of the most important findings. Healthy people whose choice of food is not restricted by financial considerations, but is determined solely by appetite and the customs of their home or community, usually consume each day food of a fuel value of 20 Calories per pound of body weight. It is exceptional to eat less than 16 Calories or more than 24 per pound so

long as only moderate amounts of exercise are taken; and many students of this subject have assumed that one requirement of diet is that the daily intake of food should have approximately this fuel value.

This view has, however, been seriously questioned by careful and competent observers, and their work seems to show that a fuel value of 13.5 Calories per pound of body weight more nearly represents the actual needs of the body. *In other words, the usual diet, with its three hearty meals a day, has a fuel value one and a half times as great as the minimum requirement of the body.* Whether the excess is or is not harmful to the body will be discussed later (see page 275).

The chief factor which influences the amount of this minimum fuel requirement is the amount of muscular exercise taken. Men at hard labor require from 20 to 25 Calories per pound of body weight, or even more; on the other hand, during the marked muscular relaxation of sleep the requirement is reduced to from 10 to 11 Calories. Exposure to cold, when not counteracted by warm clothing, similarly increases the fuel requirement.

7. The fate of fuel in excess of immediate needs. If, as was noted above, we generally eat more food than the body needs as fuel, what becomes of the excess? This question can be answered only incompletely in the present state of our knowledge. (1) Some of the food eaten is discharged undigested in the feces; and the more abundant the diet, the greater is the amount lost in this way. (2) A part of the food is destroyed in the alimentary canal, especially in the large intestine, by microbic action, and this action similarly increases with the diet. This microbic destruction of food involves the liberation of heat within the body but does not yield power for work, the excess of heat being dissipated from the skin. (3) A portion of the ingested food, notably proteins and their cleavage products (the amino

acids), leads to an increase in its own destruction in the cells of the body, just as an open fire burns more vigorously when new fuel is added. Finally, (4) a considerable quantity of food may be stored within the body. That this is true is shown by the histories of prolonged fasts in which men and women have abstained entirely from food for more than a month. Such fasters steadily lose weight, showing that the body is consuming its own substance. We may therefore pass to the consideration of the storage of material capable of meeting future nutritional needs.

II. The Food Reserve of the Body: *A*, Fat; *B*, Glycogen; *C*, Cell Proteins

8. The hoarding of nutrients in inactive forms. *A. The fat reserve.* The most obvious reserve food stored in the animal body is fat, which may appear as drops of oil in the cytoplasm of any cell. Muscle fibers, for example, contain at times large quantities of this substance, and are then said to have undergone fatty degeneration. Under normal conditions, however, the presence of considerable quantities of fat in muscle fibers or nerve cells or most gland cells is unusual. In the cells of connective tissue, on the other hand, fat is readily stored under normal conditions, and the *adipose tissue* or fat of the body is simply connective tissue whose cells are loaded with droplets of fat. Figs. 94–96, with their explanation, will show how this takes place. But while fat may be normally stored in any of the more open connective tissues, it is especially in the subcutaneous tissue, the great omentum, the mesentery, and some other situations that its chief storage takes place. From these storehouses it is drawn upon as a reserve food material when the immediate supply of food from the alimentary canal becomes inadequate for the work of the body. The exact

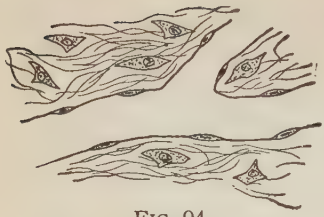


FIG. 94

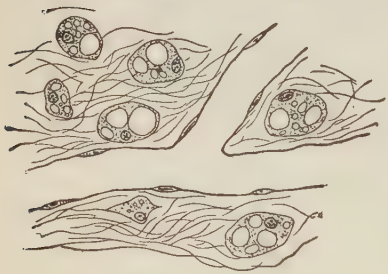


FIG. 95

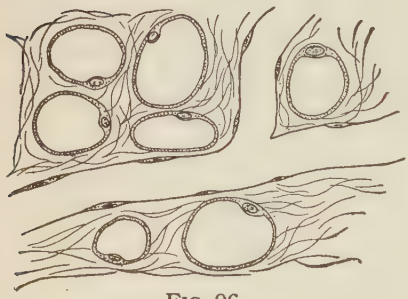


FIG. 96

FIGS. 94–96. Three successive stages in the transformation of ordinary connective tissue into adipose tissue

A portion of the capillary network is shown, surrounded by the fibers, among which are several cells. The accumulation of fat droplets in the cell cytoplasm is shown in Fig. 95, and the fusion of these upon their increase in size and number to form one large droplet, surrounded by the cytoplasm, is seen in Fig. 96

mechanism by which it is stored in a cell at one time and discharged at another is not fully understood. Some of the conditions under which it is accumulated, and some of those under which it disappears, are known; but we do not know the whole story. Some people lay up fat in larger quantities than others on the same diet and apparentlywhile doing the same amount of work, and some keep lean under conditions apparently the most favorable for becoming fat.

It was formerly believed, and is still sometimes supposed, that the animal body forms fat only from the fat of the food; that to increase in weight we must eat fat. This was disproved by a number of experiments, especially one by Liebig, who kept account, over a long period, of the fat in the food supplied to a cow, and found that the fat given off in the cow's milk far exceeded

that in her food. In another experiment four pigs out of a litter of eight were killed and the total amount of fat in their bodies determined. The other four pigs were fattened for a time, then killed and the fat in their bodies determined. Assuming that the second set of four pigs originally had the same quantity of fat as the first four, the difference between the two quantities of fat found would give the quantity of fat the last four had stored up. Meantime, strict account had been kept of the fat supplied in the food of the last four, and it was shown that for every 100 parts of fat fed to them these pigs had laid up 472 parts of fat. They had evidently *manufactured fat from some substance other than the fat* in their food.

9. Fats can be stored from fats and carbohydrates in food. There is no doubt that fat may be both *stored away* and *manufactured* from the fats in the food. There is also no doubt that large quantities of fat may be and often are manufactured and stored from the carbohydrates (sugars, starches, and so forth) of the food; so that, while there is some truth in the idea that one may get fat by eating fat, it is equally true that one may get fat by eating other foods.

10. The question of fat being stored from protein. Since fats can be made from carbohydrate, and carbohydrate in turn from protein, there is the possibility that the body may manufacture and store some of its fat from this source. Yet proof is wanting to establish that this is done; it is very doubtful whether such a transformation can take place to a useful extent and it is probable that it does not normally occur at all in the mammalian body.

Fats, then, are manufactured readily from fats and carbohydrates and sparingly, if at all, from proteins. Their disappearance during starvation, when they are drawn upon to supply power and heat for the body, shows that they serve as a true reserve food material. They are a kind

of food capital or hoard, saved and laid up by the body against a "rainy day."

11. The hoarding of nutrients in inactive forms. *B. The carbohydrate reserve.* In many cells of the body, but especially in those of the liver and to a less extent in those of the skeletal muscles, there is found a carbohydrate substance known as *glycogen.* This substance belongs to the same group of carbohydrates as starches and dextrins (see Chapter VIII), and is sometimes called *animal starch.* Like them it is changed into sugar by the action of saliva and pancreatic juice, whence its name (γλυκύς, "sweet"; -γενής, "producing"). The same change occurs on the death of the cells in which it is contained, the sugar thus formed giving to such tissues a sweetish taste. This is often noticed, for example, in liver and in scallops (the shell muscle of *Pecten*). The total amount of glycogen in the human body may exceed 700 grams (23 ounces), one half of which is concentrated in the liver and the other half scattered about in the other tissues of the body.

Experiments have shown that glycogen is not formed from the fat in food; that it is formed in small quantities from protein; while its chief source is the carbohydrates of the food.

The blood may be said to be always sweet, its constant percentage of sugar (1 to 2 grams per 1000 cubic centimeters or 0.05 ounce per quart of blood plasma) being a striking fact, and one that we should hardly have anticipated. One might suppose that the sugar in the blood would increase, as does the amount of fat, during active digestion and absorption, and that it would diminish after digestion had ended. As a matter of fact, the amount of sugar in the blood remains practically constant both during and after the completion of digestion, and this despite the fact that the tissues are constantly abstracting sugar from the blood. Evidently the blood must be supplied with sugar from some

other source than the alimentary canal, and there must be somewhere in the body a compensating mechanism controlling the sugar supply of the blood.

Experiments have shown that sugar is absorbed from the alimentary canal entirely by the intestinal blood vessels. It must pass, therefore, through the liver by the portal vein (see Fig. 67) before going to the rest of the body. The liver, thus standing at this great gateway to the circulation, would seem to act as the carbohydrate storehouse, or savings bank, of the body. Any excess of sugar in the portal blood is there transformed into glycogen and deposited, saved until it is needed, and then "paid out," as sugar, when the ready supply is exhausted. Other tissues doubtless aid in preventing an undue richness of sugar in the blood, acting likewise as temporary storehouses for this form of food.

12. Carbohydrate can be stored from protein. It has been stated that glycogen may be formed from protein. This is because the body can and does constantly form sugar (dextrose) from protein. Experiments have shown that about half of the protein eaten may in this way be transformed into sugar, the greater part of which is ordinarily oxidized as fuel; but in case there is an excess over and above fuel needs, this excess of sugar is stored as glycogen by the liver and other organs, just as the excess of sugar absorbed from the alimentary canal is so stored. The formation of sugar (and consequently of glycogen) from fat, on the other hand, is negligible.

In this formation of sugar from protein the body obviously has an additional means of supplying its carbohydrate needs when the sugar delivered to the blood by absorption from the alimentary canal is inadequate.

13. The hoarding of nutrients in inactive forms. *C. The protein reserve.* We have seen that fats and carbohydrates may be stored in the body in inactive forms, and that thus

between periods of absorption, and even during starvation, provision is made for a continuous supply of these nutrients. Proteins must also be continuously supplied for the maintenance of the body under all conditions, for they are necessary both as sources of energy and as structural materials for the repair of the organism. This raises the question as to whether there is a similar storage of protein in some inactive form. Though many physiologists have investigated the question, it has not yet been conclusively answered. No supply of inactive protein is visible as in the case of fat and glycogen, and none is detectable by chemical means. While chemical analysis of the lifeless cell shows that proteins make up by far its largest constituent,[1] there is no ground for thinking that this cell protein exists in any other form than as a living constituent of the cell substance; that is, as the living protoplasm. There is no conclusive evidence of protein being stored simply as a reserve. The increase in the protein content of an organ, under favorable conditions of nutrition and exercise (for instance, the growth of the muscles of the arms and chest following suitable training), is not an example of storage of inactive protein.

During starvation, protein is steadily lost from the body, as is shown by the fact that urea and other protein derivatives continue to be eliminated by the kidneys. Since the protein is not eaten and hence not absorbed, it must be derived from the tissues. This loss of protein can be reduced by the feeding of carbohydrates and fats; but, though they be supplied in amounts abundantly sufficient to meet the fuel needs of the body, this will not entirely

[1] The following analysis of muscle cells (lean of meat) is typical:

Water	75 parts
Solids	25 parts
Protein	21 parts
Salts	1 part
Fat, connective tissue, etc.	2 parts
Other extractives	1 part

prevent protein loss — an irreducible minimum of protein disintegration must continue until death. Throughout the course of starvation there is evidence of an attempt on the part of the body to conserve its proteins. As regards the excretion of the products of protein decomposition, we may divide the period of starvation into three stages: (1) a few days of increased excretion; (2) a long interval of decrease to a fairly constant point; and (3) a final increase just before death. The following deductions have been drawn, based on the supposition that the quantity of these products is the measure of protein decomposition: at the beginning of starvation, there is some protein derived from the last meal and not yet synthesized to living tissue, so the body uses this as a more ready source of energy than the stored fat and carbohydrate; after this unsynthesized protein has been used up, it is easier to derive energy from the carbohydrates and fats than from the living protein; and finally, having consumed the stored fats and carbohydrates, energy must be obtained at the sacrifice of the living protein. We can only conclude that the disintegration of protein within the body is an inevitable part of the chemical activity of the cells, and that, in the absence of a supply of the protein products of digestion, the body takes protein from its own living substance. Hence protein is an indispensable article of diet. The student will, moreover, recall the fact that while carbohydrates and possibly fats may be made from protein, protein cannot be manufactured from the nonprotein nutrients. This obviously follows from the fact that fats and carbohydrates are lacking in nitrogen and sulphur, two essential elements of the protein molecule.

14. Increase of protein in the food increases protein destruction by the body. One peculiarity of the behavior of protein in the body is that it automatically limits the accumulation of any large amount of stored protein. As soon as we increase

the protein in the food, there is an increase of protein disintegration in the body, and after a few days protein disintegration equals the greater protein consumption. Instead of storing the additional food protein or even part of it over any great length of time, the body soon destroys all the protein eaten. It is for this reason that, while animals may be fattened to a remarkable extent by proper feeding, it is not possible to secure a corresponding increase of protein material of the muscle, or lean meat. The accumulation of protein is self-limited.

In two physiological states the increase of protein used by the body is a marked phenomenon, namely, during growth and during convalescence from wasting disease (or after a period of prolonged fasting). It would seem that there is a certain maximum content of protein-like substances in the cell, and that it is not possible, even by the most abundant eating of protein, to exceed this amount.

It follows from the above that overabundant protein eating must result in the production of increased protein waste within the body. In the first place, the greater the quantity of protein eaten, the greater will be the microbic destruction of protein within the intestines and especially in the large intestine. Not only is the protein so destroyed largely useless to the body, but, in so far as its microbic destruction involves putrefactive changes, harmful products may be formed from it. In the second place, that portion of the protein which escapes microbic action and is absorbed into the blood in the form of digestive products (amino acids and peptides) disintegrates in the cells with the formation of wastes. Both these processes increase the amount of waste to be eliminated, chiefly by the kidneys. It has been urged that this overburdens the kidneys and causes disease of these organs. While convincing proof has perhaps not been given that a healthy kidney may be

injured in this way, it is certain that a diseased or even a temporarily impaired kidney may suffer when such excessive work is thrown upon it.

III. Food as the Material for Growth, for Repair, and for the Manufacture of Special Products of Cell Activity

15. Complexity of the chemical composition of living cells and of the products of their manufacture. In the first subdivision of this chapter we have considered food as fuel. We are now in a position to consider some of the more important features of the other great function of food, namely, as the material for the growth and repair of living cells and for the manufacture of the special products of cell life — the secretions (internal and external), the hormones, and all other substances produced by the body for special purposes.

The living cell is an extremely complex machine, into the construction of which enter numerous compounds of diverse chemical nature. Formerly there was a tendency to regard the cell as composed essentially of protein; but the increase of our knowledge has shown that there are other essential constituents, notably (in addition to water and inorganic salts) a group of compounds known as lipoids, or lipins, substances which more or less resemble fats in their physical characters, although not always in chemical structure. The cell nucleus also contains special material of still different chemical composition. The chemical properties and the physiological significance of these cell components are far too complicated subjects for discussion in this work; we merely wish to emphasize the complexity of the combinations and the variety of chemical compounds concerned. (See page 47.)

We are impressed with the same diversity of chemical structure in the secretions, hormones, and other material manufactured by the body for special purposes. The student has only to recall the examples of these already mentioned — the enzymes of the digestive juices; the internal secretions of the adrenals, thyroids, pituitary, and pancreas; secretin and other hormones; mucin; and hæmoglobin — to realize that the food must furnish material out of which to manufacture compounds of the greatest variety of chemical structure; and for this purpose the greatest variety of material must be furnished in the food.

16. The unique position of protein. Considerations such as the above give a glimpse into the unique value of protein food. While the body is supplied by the carbohydrates only with dextrose, for the greater part, and by the fats with glycerin and salts of the fatty acids (soaps), — all of them very simple substances, — it is, on the other hand, supplied by the proteins with amino acids in great variety and complexity of chemical structure (p. 122). The possibilities of chemical construction, or *synthesis* (as it is generally called), are thereby greatly increased in the case of the derivatives of the proteins. While any one of the above three nutrients could fill the requirements as regards the production of energy, only a chemically complex nutrient like protein could serve for the construction of the proteins of the living cell and for the formation of the varied products of cell manufacture. Protein is therefore unique in that it is a source both of fuel for the production of energy and of structural materials for growth and repair.

Protein is also unique among the nutrients in that the body can make other nutrients from it. It is a well-established fact that large quantities of sugar (dextrose) may be made from protein, and we can therefore understand how a dog living on the leanest sort of meat (protein) can do without

carbohydrate in the diet. It is also possible that at least small amounts of fat may be derived from protein through this intermediate stage of sugar, for fat may be made from sugar.

17. Variations in the nutritional value of individual proteins. We have seen that proteins yield not only energy for the activities of the organs but also materials for their growth and repair. Until comparatively recent times all food proteins were regarded as having equal value in nutrition, with the single exception of gelatin, which has long been known to be incapable of meeting the protein needs of the body. However, the discovery that some food proteins are lacking in one or more of the amino acids, and that the same amino acid may occur in very small amounts in one protein and very large amounts in another, suggested to two American physiologists, Mendel and Osborne, the idea that different proteins may have very different values in nutrition. They therefore fed rats and mice on diets ample in fats, carbohydrates, mineral salts, and water, but containing only one protein — and this one in isolated, purified form. They found that some proteins (zein from corn meal, as well as gelatin) failed entirely to nourish the animals, as was shown by the steady loss of weight; that other proteins (gliadin and hordein from the flours of wheat and barley) would maintain an adult animal in good condition without loss of weight but would not produce growth in a young animal; and that a few proteins (such as casein from milk) not only sustained fully the adult animal, but also promoted the growth of young ones in a perfectly normal manner. Other investigators have shown that a diet deficient in hæmopyrrol, a derivative of a protein found in green leaves, leads to the development of anæmia, a condition characterized by an insufficiency of hæmoglobin; and this is believed to be due to the lack of a specific structural unit needed in the manufacture of hæmoglobin.

On the basis of these experiments[1] we may therefore distinguish between (1) proteins which may provide for both growth and maintenance, (2) proteins which will provide for maintenance but not for growth, and (3) proteins which will provide for neither maintenance nor growth. Further studies have shown that the nutritional limitations of the last two classes of proteins are due to the fact that they are lacking in certain amino acids or else contain them in very small amounts; for if these amino acids were added to the diet, growth and maintenance became normal. The reason for this becomes clear on the assumption, already made in our discussions of digestion and nutrition, that the value of protein as food lies in the fact that it yields a great variety of amino acids, each necessary to some chemical manufacturing process of the living cell.[2]

18. The value of a mixed diet. As a matter of fact no one tries to live on a single protein. Meat contains at least two; eggs, three or more; milk, two; the cereals, two or more each. By taking a mixture of these in our food, the deficiency of one protein in amino acids is made up by the excess of the same acid in another. For this reason we can completely meet the protein needs of the body on a mixed diet with a far smaller total intake of protein than if the diet contained only one protein.

The same consideration applies in a larger way to the food materials as a whole. An adequate diet must contain all the nutrients (p. 113) in sufficient amounts. An individual food substance is likely to yield an excess or deficiency in one or more of the nutrients. Meat is chiefly protein; bread, chiefly carbohydrate; and butter, chiefly fat. Bread made from white flour is deficient in mineral salts; and olive oil

[1] Some have questioned the conclusion reached in the above experiments. There is a similar lack of growth when certain vitamins are withheld; and, as Howell states, there may be other factors, at the present time undetermined.

[2] See pages 47, 124, 265, and 266.

and polished rice are deficient in certain vitamins. An excess or deficiency in any one nutrient is more likely to be avoided when the diet is composed of several kinds of food than when it is unduly restricted.

IV. Other Indispensable Constituents of the Food: Inorganic Salts; Vitamins

In addition to the proteins, fats, and carbohydrates, which together make up almost the whole (when estimated in the dried state, 96 to 98 per cent or even more) of the food we eat, two other groups of substances are required in much smaller quantities, but they are none the less absolutely indispensable. These are the inorganic salts and the vitamins.

19. Inorganic salts. Compounds of mineral matter occur both in the living cells and in the blood and lymph. Their presence is not merely accidental; they are as essential as other nutrients. The most important are sodium, potassium, magnesium, calcium, iron, and iodine which are in combination with chlorine, phosphorus, carbon dioxide, and the organic matter of protoplasm. Some of them are simple salts, such as sodium chloride (common salt), sodium bicarbonate (cooking soda), and calcium carbonate (limestone rock); others are complex protein derivatives, such as hæmoglobin.

The functions performed by the mineral substances are extremely varied. Some of these will be cited by way of illustration, as follows: (1) Sodium chloride is needed to regulate the fluid exchanges and the water content of the cells. (2) Sodium bicarbonate serves to combat the development of acidity in the tissues. (3) Calcium, in various combinations, is essential to the hardness and rigidity of the teeth and bones, to the proper nervous control of the

muscles, and to the clotting of the blood. (4) Iron is a constituent of hæmoglobin, the oxygen carrier of the blood, and hence is indispensable to the supply of power and heat. (5) Iodine is a necessary constituent of the internal secretion of the thyroid gland (thyroxin), which is a regulator of the chemical processes of the body.

These salts, so necessary to the body, are being constantly excreted in the urine, the perspiration, and the feces. If their loss were not made good, ill health and even death would ensue. Most food and drink contain mineral substances, and our usual varied dietary furnishes an ample supply to make good the loss by excretion. A limited dietary may, however, be notably deficient in some, or most, of the inorganic compounds. This is true of bread made of white flour, and of potatoes cooked without their skins; while, on the other hand, the green parts of plants, the peelings of vegetables and fruits, and whole-grain cereals are particularly rich in the important mineral salts.

20. Vitamins. There are certain other substances, found in small quantities in many food materials, which are necessary to the well-being of our bodies. To them the general name of *vitamins* has been given. Their exact chemical nature is still a matter of investigation, but it has been determined that they are not proteins, fats, carbohydrates, or inorganic salts.

The physiological action of these substances is not yet clear, but it is definitely known that they furnish the tissues with some material indispensable for the secretory processes. Though required in much smaller quantities, they are as necessary to these processes as the proteins and carbohydrates themselves.

Vitamins are widely distributed among our common food materials, being especially abundant in fruits, vegetables, eggs, milk, and cod-liver oil. Many of them are destroyed

by high temperatures, for instance those temperatures used in canning, sterilizing, and frying; and they are largely removed from vegetables which have been cooked without their skins, and from cereal grains which have had their outer portions (bran) removed in the attempt to produce the whitest possible flour or rice. It follows that whole-wheat flour and graham flour contain vitamins, while the very white flour, which the housewife prefers, is deficient in them.

Our knowledge of the essential part played by the vitamins, as well as of their presence or absence, has been acquired in two ways: (1) from the observation that certain diseases, which have developed in persons whose dietary has consisted of only a few foods, can be cured by adding other foods to the diet; and (2) from the study of the effects produced on animals by withdrawing certain articles from their dietary, or by limiting it in variety. A consideration of beriberi will be instructive in this connection. This is a common disease in many Eastern countries where rice forms the chief food. It is characterized by grave disorders of nutrition, and in severe forms the nerve fibers undergo degeneration, so that paralysis of the skeletal muscles develops. It was found that beriberi occurred chiefly among those who used polished rice, that is, rice from which the dark outer portion of the grain had been removed in the process of milling, in order to give a whiter grain; it seldom developed in those using the whole rice grain (that is, the unpolished rice). It was furthermore discovered that from the rice polishings something could be extracted which, when administered in very small quantities, would cure the disease. Finally, it was discovered that a similar disease (polyneuritis) could easily be induced in fowls by feeding them on a diet consisting solely of polished rice, but that it did not develop when the extract of rice polishings was

administered to the fowls, even though their food otherwise consisted wholly of polished rice. This extract would, moreover, cure the disease when it had once developed.

The same disease has occurred in Newfoundland, where a community was shut off during the winter from its usual food supply, and white bread constituted for too long a time the chief food. A similar or perhaps identical disease has been found among people living exclusively upon canned goods, the sterilization by high temperatures having destroyed the vitamins.

In the days of sailing vessels, scurvy, a disease of malnutrition, often developed on long voyages, despite a diet which contained an abundance of protein, fat, carbohydrate, and salt; and it was found that this disease could be prevented by the use of fresh limes or freshly cooked vegetables. There is little doubt that here again we are dealing with a disease analogous to beriberi.

Whether one group or more than one group of compounds is concerned here is not known. It is clear, however, that we have in the above facts proof of some essential constituent or constituents of the diet other than the usual nutrients. In all the above cases it must be clearly understood that there was no harmful constituent in the foods mentioned — canned foods, polished rice, white bread, and the like. The trouble lay in the absence from the food of an essential constituent of the diet. No harm would result, for example, from a diet of canned meat, white bread, and fresh vegetables; for the fresh vegetables would supply the necessary vitamins. It is only when the diet consists almost exclusively of foods deficient in vitamins that trouble results.

Vitamins have been classified in many different ways. Five of the most commonly accepted groups, together with the food materials containing them and the diseased

conditions appearing when food is deficient in them, are as follows:

1. **Vitamin A:** essential to growth and the maintenance of the body weight; without it, the animal ceases to grow and becomes thin; occurs in milk, animal fats (except lard), and leafy parts of vegetables.
2. **Vitamin B:** essential to the nutrition of nervous tissue; without it, the animal develops a paralysis with atrophy of the muscles; present in yeast, eggs, peas, beans, and cereals.
3. **Vitamin C:** essential to the nutrition of the skin and mucous membranes; without it, the skin and lining of the mouth become sore and bleed badly; found in oranges, lemons, tomatoes, and green leaves.
4. **Vitamin D:** essential to the development of the bones and teeth; without it, the bones fail to become hard and rigid and the teeth are defective; occurs in egg yolk and cod-liver oil.
5. **Vitamin E:** essential to procreation; without it, both male and female animals become sterile; present in lettuce, whole cereals, egg yolk, and beef liver.

21. A deficiency in certain vitamins may be made good by other means; ultra-violet light. Certain food materials which are not effective in preventing bone diseases (rickets) may become effective after exposure to ultra-violet light, invisible rays of a wave length shorter than those of visible light. That is to say, some substances may be artificially endowed with the properties of vitamin D; although we do not hold that the vitamin itself has been created. Furthermore, an animal exposed to ultra-violet light, or to direct sunlight which contains it, will not develop rickets, even though it be not protected by the ingestion of foods containing vitamin D. This topic will be presented more fully in a subsequent chapter.

V. The Proper Daily Intake of Protein

22. The economic and the physiological question. The proper amount of protein in the diet is both economically and physiologically important. Since foods rich in protein

— meats, eggs, dairy products, and so forth — are among the more expensive foods, for a family with limited income it is often a practical question how much of these foods must be used to assure proper nourishment of the body. In this book we are more directly concerned with the physiological effects of low, moderate, and abundant protein diet, but the answer to this question also gives the answer to the economic question, since the problem in the latter case is to keep down the consumption of the more expensive foods to the lowest level which is consistent with adequate nutrition.

It is comparatively easy to determine whether the fuel value of the diet is adequate. If it is insufficient, loss of weight inevitably results; if it is excessive, and especially if it is excessive in fat and carbohydrate, there is apt to be increase of weight. An equilibrium of total intake and output for months usually indicates that the fuel needs of the body are being met. Equality of intake and output of protein, on the other hand, does not prove that the protein of the diet is what it should be, for the body breaks down all the protein it consumes, whether the amount be excessive or not. We can, however, determine by dietary studies what is the usual consumption of protein by different classes of people, and also what is the lowest intake upon which protein equilibrium may be maintained in the body.

23. The usual and the minimum intake of protein. When the choice of food is not restricted by economic or other consideration, but is determined solely by appetite or the customs of one's home or community, the protein intake of an adult healthy man usually varies between 100 and 150 grams daily. This is equivalent to from 500 to 750 grams (1 to 1½ pounds) of lean meat, although of course the protein is not all taken in the form of meat. On the other hand, experiments have shown that men may live for

years in good health on a protein intake of from 40 to 50 grams daily without destruction of the protein of the body.

If, then, an adult man can maintain protein equilibrium on from 40 to 50 grams of protein daily, but ordinarily consumes two or three times this quantity, the question arises whether the additional 50 to 100 grams are to any extent harmful. Certain students of this subject believe that such is the case, while others contend that an excess of protein is necessary to provide a margin of safety. There can be no question that the health of many people, especially when leading sedentary lives, has been greatly improved by reducing the consumption of protein to 60 or 70 grams, or even to 40 or 50 grams daily. To what is this improvement due? Is it because the digestion of so much protein by the adult is necessarily harmful? (See page 278.)

24. Possible harm and possible advantage in an abundant protein diet. We can readily see at least two ways in which the greater protein intake may be harmful. In the first place, it involves greater danger of incomplete protein digestion in the small intestine, and the consequent delivery by peristalsis of excessive amounts of protein to undergo microbic putrefaction in the large intestine. In general a decidedly offensive odor of the feces suggests that more protein[1] is being eaten than can be properly digested, and justifies at least an experimental reduction in the protein of the food. It must, however, be remembered that putrefactive odors may be due to other causes than excessive protein diet (impaired digestion of fats, for example), and, on the other hand, there may be excessive putrefaction and yet the feces have no very offensive odor because the compounds responsible for odor have been destroyed within the body.

[1] The substances responsible for the offensive odor are almost entirely derivatives of protein.

In the second place, the larger protein diet with its increase of protein wastes in the tissues themselves (as contrasted with the alimentary canal) involves a greater burden on the organs of excretion. This burden may fall not alone on the kidneys, which finally discharge these wastes from the body, but also upon other organs in which the waste products are prepared for final removal from the blood by the kidneys. Convincing proof has, however, not been given that these organs, when in a healthy condition, are injured by the work of caring for more than the waste of a low protein diet. A somewhat analogous case is that of muscular activity. This too must be limited or even given up altogether in some diseased conditions, lest some undue burden be placed upon the organism; but in health the body is actually benefited by the "burden" even of vigorous muscular activity.

The further question then arises whether there is any possible advantage in a liberal protein diet. It is certainly not needed for power or for fuel; it may, however, be plausibly urged that thereby we insure an abundance of each amino acid needed for the formation of the innumerable chemical products manufactured in the body. When an engineer builds a bridge, he does not build it just strong enough to sustain the expected load; he allows a liberal "margin of safety." Similarly, it is not a desirable economic condition if one's income each week is just enough to meet necessary expenses, for this does not allow for the unexpected emergency which we cannot foresee. So it has been urged and, it would seem, reasonably urged that it is better not to diminish protein intake, as a rule, to the irreducible minimum of 40 to 50 grams daily. While 100 to 150 grams is almost certainly far more than is necessary to secure the proper margin of safety, it may well be wiser to use 20 or more grams above the minimum; that is to say, a protein

intake of 70 grams corresponds with what, in the present state of our knowledge, may be regarded as a conservative estimate.

Infants and rapidly growing children need relatively more protein than adults. The protein of the usual adult diet is about 13 to 15 per cent of the total fuel value of the food; in milk, the sole diet of a baby, it is 20 to 25 per cent. During convalescence from wasting diseases the diet should be as rich in protein as is consistent with its proper digestion and utilization by the body, because the additional amount is needed for reconstruction of the tissues.

25. Food values of some common foods. The following table (from Joslin) will be found useful in forming an estimate of the relative content in certain foods of protein, fat, and carbohydrate, and also of the fuel value of these foods.[1]

30 Grams (or 1 Ounce) contain Approximately	Protein	Fat	Carbohydrate	Calories
	Grams	*Grams*	*Grams*	
Oatmeal, dry weight	5	2	20	120
Cream, 40 per cent	1	12	1	120
Cream, 20 per cent	1	6	1	60
Milk	1	1	1.5	20
Brazil nuts	5	20	2	210
Oysters (six)	6	1	4	50
Meat (uncooked, lean)	6	3	0	50
Meat (cooked, lean)	8	5	0	75
Bacon	5	15	0	155
Egg (one)	6	6	0	75
Vegetables	0.5	0	1 or 2	6 or 10
Potato	1	0	6	25
Bread	3	0	18	90
Butter	0	25	0	225
Fish	5	0	0	20
Broth	0.7	0	0	3
Small orange or half a grapefruit	0	0	10	40

[1] An individual at rest requires about 25 Calories per kilogram (2.2 lb.) of body weight per twenty-four hours, equivalent to approximately 1 Calorie per kilogram per hour.

26. Example of a diet of moderately low protein and fuel value. Below is given an example of three meals which would give the moderate protein intake referred to on page 276. The fuel value also corresponds approximately, for a man of 150 to 160 pounds, to the fuel value of 13.5 Calories per pound of body weight referred to on page 256.

Breakfast. Bread, 38.7 grams; tea, 146 grams.

Lunch. Bread, 97.5 grams; butter, 31.5 grams; sweet potato, 108.7 grams; spaghetti, 82.5 grams; peaches, 89.4 grams; coffee, 210 grams; sugar, 21 grams.

Dinner. Bread, 75 grams; butter, 21.5 grams; roast beef, 116 grams; lemon pie, 188.5 grams; coffee, 210 grams; sugar, 21 grams.

Protein in food	70 grams
Fuel value	2334 Calories

30 grams = 1 ounce, or $\frac{1}{16}$ pint.

CHAPTER XIV

SENSE ORGANS AND SENSATIONS

1. The human mechanism a conscious mechanism. Thus far we have repeatedly compared the human mechanism with lifeless mechanisms, and the points of similarity are most interesting and instructive. In the supply of power, the elimination of wastes, the interdependence and coöperation of parts, the adjustment to changing conditions, and in many other respects, the resemblance holds good. But in one respect there is no likeness whatever. When a human mechanism is not in good working order or is tired, it may be aware of the fact; when an engine is damaged in any way, the engine does not know it. Events taking place in the living animal body arouse in it, and in it only, *conscious sensations.*

Sensations are always called forth by the condition of some organ or by the condition of the body as a whole. When we have passed several hours without food, we feel hungry; or without drink, we feel thirsty; when anything touches the skin, a sensation of touch is aroused; if it presses very hard, that part of the skin feels painful; if the tongue is acted upon by sugar or salt, we get a sensation of taste; if light enters the eye, it produces conditions in that organ which arouse in us sensations of color. *In all these cases the conscious sensation is due to the condition of some part of the body.*

2. The reference of sensations. Sensations may be classified, according to whether we refer them to our own bodies or to other objects, as *internal* and *external.* Thus, if in

driving a nail the hammer misses the nail and hits a finger, we refer the pain to the finger and not to the hammer; and we similarly refer sensations of hunger and thirst to the body and not to external objects. If, on the other hand, the skin is cooled by a piece of ice, we do not say that the skin is cold, but that the ice is cold; we refer the sensation to the external object which causes it, not to the skin in which it actually originates. In the case of the sense of sight, this reference of the sensation to the external object which sends light into the eye is so complete that unless we stop and reflect we do not realize that it is the condition of the eye of which we are conscious rather than the condition of the external object at which we are looking.

3. Sense organs. A few sensations, like pain, are aroused by the condition of most, if not all, parts of the body; there is no one organ set apart to produce them. Some, like hunger, although at times more or less general in origin, are commonly aroused by the condition of some one organ[1] which ordinarily performs other functions. Other sensations arise in organs set apart for the purpose and constructed to respond to only one kind of stimulus (*special sense organs*, or organs of special sensation). To this latter class belong the eye, the ear, the olfactory mucous membrane of the nose, the touch organs in the skin, and so forth. We therefore speak of *general sensations* and *special senses*, although no sharp line of division can be drawn between the two.

4. The brain the seat of sensation. In all cases, however, sensation, although originating elsewhere, is developed in the brain and not in the sense organ. If the optic nerve be cut, blindness ensues, although light falling on the retina produces the same effect in the eye itself as when the nerve is intact; it even starts nervous impulses toward the brain; but, since these impulses go no farther than the cut, they

[1] In the case of hunger, the stomach.

excite no sensation of light. And the same thing is true of other sensations. Conversely, after the amputation of a limb it often happens that sensations are felt as if they came from the lost member. In this case the stump of the cut nerve is stimulated in some way, and the impulses thus sent to the brain excite the same sensations as if they came from the usual endings of the nerve. When one hits his "funny" or "crazy" bone (that is, directly stimulates the ulnar nerve) the sensations developed in the brain may be referred to the fingers in which the nerve originates.

In the development of every sensation, therefore, we have to distinguish between (1) the production of the nerve impulse in the sense organ, (2) the passage of a nervous impulse from this organ to the central nervous system, and (3) the events which the arrival of the nervous impulse excites in the brain. It is only the last (3) that, strictly speaking, we can call *sensation*. The sense organs and their afferent fibers are merely tributary mechanisms. The former are, so to speak, transformers to change light, odor, sweetness, etc., into nerve impulses which can be conducted along the latter to the brain. An analogy might be made to the mouthpiece of the telephone, which converts the sound produced by the human vocal organs into electrical waves which can be conducted along a wire to a distant point. We are not aware that it is the brain which is active, for we refer the sensation either to the organ or to some external object.

I. The Eye and Sight

Sight is one of the most highly specialized of the senses. The eye is the only organ in which originate sensations of light or color, and it is a wonderfully constructed apparatus, the function of which is to stimulate the optic nerve by transforming rays of light. It is essentially a living camera

in which, by means of a lens, an image of things around us is formed upon the retina; just as in the photographer's camera the lens forms an image on the ground glass or on the sensitive plate or film.

5. Structure of the eye. The eyeball (Fig. 97) consists of three concentric coats surrounding and inclosing transparent

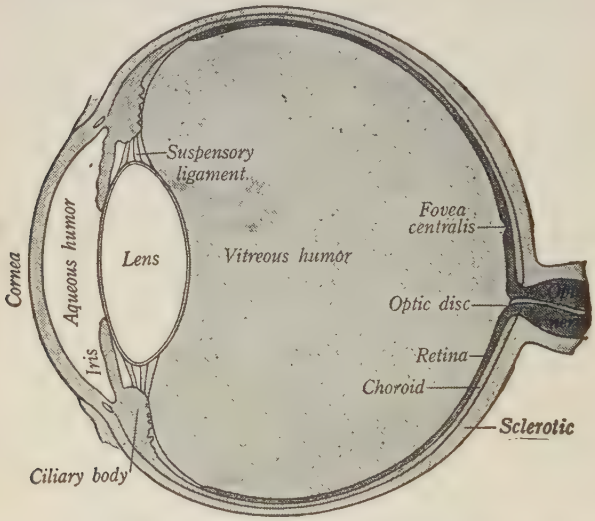


FIG. 97. A schematic representation of a section through the eyeball

substances through which rays of light pass to the retina. The outer coat, or *sclerotic* (the white of the eye), is composed of very tough, dense connective tissue and forms the protecting wall of the eye. A small area of the front part of this coat is transparent, and this is known as the *cornea.* Inside the sclerotic is the middle coat, or *choroid,* richly supplied with blood vessels and containing in its connective tissue large quantities of dark-brown pigment, which prevents the passage of light into the eyeball except through the cornea. The choroid lines the sclerotic everywhere

except in front, where it leaves the sclerotic and stretches behind the cornea as a kind of curtain, the *iris* — that part of the eye which is black, brown, gray, or blue. The dark, round opening or hole in the iris is called the *pupil*, the size of which may be increased (dilated) or reduced (contracted) by the action of muscles lying buried in the iris. Peripheral to the iris is the muscular and glandular *ciliary body*, while behind the pupil is the *crystalline lens*, which serves the very important purpose of adjusting the rays of light to the retina. The *retina* is a transparent membrane, not more than one eightieth of an inch in thickness, which lines the inner surface of the choroid at the back and sides of the eyeball. It is the inner coat of the eye and is sensitive to the stimulation of light, which it converts into nerve impulses.[1] Here also begin the fibers of the optic nerve, which passes through the choroid and sclerotic coats on its way to the brain. There is at the site of the formation of this nerve a small craterlike area, the *optic disc*; at a short distance, lateral to this and in the line of direct vision, is a tiny depression, the *fovea centralis* ("central pit"), which is the region of most distinct vision, where the image must be received in order to get the clearest vision of an object. Finally, attached to the outer surface of the sclerotic, are six small muscles, through whose activities the eyeballs are moved. These and other parts of the eye may be easily seen by dissecting the eye of an ox or a sheep.

For normal vision, there are necessary very exact adjustments in each eye and a very delicate coördination between the two eyes. Accordingly, we will study vision from the standpoints of (*A*) one eye used by itself (monocular vision) and (*B*) both eyes used simultaneously (binocular vision).

[1] The student is doubtless already familiar with the fact that one form of energy may be converted into another; for example, the light of the sun into heat, radio waves into music, and so forth.

A. MONOCULAR VISION

6. The pathway of light from the object viewed to the retina: the visual axis. It was noted above that the retina is the coat sensitive to light. The pathway through which the rays of light are transmitted to it from the object viewed is called the visual axis (Fig. 105). The rays must pass successively through the cornea, the aqueous humor of the anterior chamber, the pupil, the lens, and the vitreous humor of the posterior chamber.

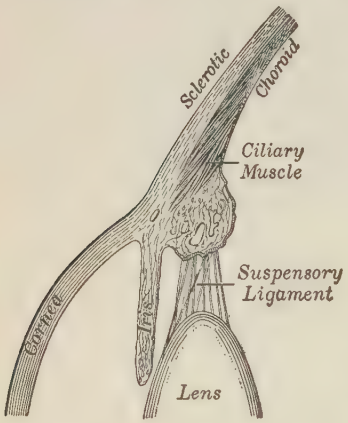


FIG. 98. Vertical section through the ciliary region of the eye

Showing the structures concerned in accommodation (see section 7)

The mere transmission of the rays reflected from an object is not all that is effected in the pathway — the rays must be (1) accurately focused, so that a distinct image will be formed, (2) adapted in intensity or brilliancy, and (3) directed on the fovea centralis for clear vision. The first of these tasks is accomplished by the lens and the muscle of accommodation; the second, by the iris and the muscles for changing the size of the pupil; the third, by the muscles which move the eyeball. The separate mechanisms involved must be coördinated by means of the nervous apparatus.

7. The lens and the muscle of accommodation. The *lens* is a biconvex, transparent, compressible, and elastic body fastened by a circular ligament *to the choroid coat* immediately behind the iris. The lens and its suspensory ligament thus divide the eye into two distinct chambers: the *anterior chamber*, in front of the lens and behind the cornea, filled

with a watery fluid, the *aqueous humor*; and the *posterior chamber*, behind the lens and surrounded by the retina, filled with a jellylike, transparent substance, the *vitreous humor* (Figs. 97, 98).

The choroid coat is elastic, and the vitreous humor "overstuffs" it and keeps it always somewhat stretched, hence it constantly exerts a steady, elastic pull or tension on the ligament of the lens. This tension flattens the compressible lens (that is, makes it less convex), and the lens is always in this flattened condition in the resting eye, as, for example, when one is asleep. The same condition should obtain, as we shall learn, whenever we are looking at distant objects.

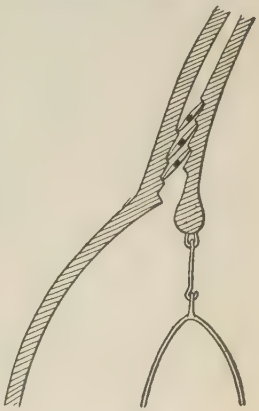


FIG. 99. Diagram of the mechanism of accommodation

The ciliary muscle is represented as three fibers passing obliquely from the sclerotic to the choroid

The pull of the stretched choroid on the lens is, however, overcome at times by the action of the *ciliary muscle*. The fibers of this peculiar muscle originate in the sclerotic coat around and just outside the cornea and diverge radially outward and backward to end in the choroid beyond the attachment of the suspensory ligament of the lens. Fig. 99 shows how the contraction of this muscle, fixed as it is near the cornea, must draw the choroid forward and so ease the pull of the latter on the ligament of the lens. When this happens, the lens, owing to its own elasticity, assumes its independent (more convex) shape.

The curvature of the lens is thus variable and is determined by the action of this muscle of accommodation. When the ciliary muscle is relaxed, the lens is kept flattened by

the pull of the choroid on the ligament; when the muscle contracts, this pull is eased (or slacked) and the lens becomes more convex. The entire operation is known as *accommodation*, which may be defined as the power possessed by the eye to adapt itself to vision at different distances. We may now inquire what part accommodation plays in the act of seeing.

8. The formation of an image by a lens. The eye is a camera, in that it forms on the retina an image of objects in front of the cornea; and it is the first essential of clear vision, just as it is the first essential of photography, that this image be sharp, or at least distinct. A simple experiment will show that clear vision of near and of distant objects cannot be had by the eye at the same time. Hold up a pencil or a pen about ten inches from the eye and look first at it and then at some object far away. Both can be seen, but only one at a time clearly, and often *an effort is required to shift from the far to the near object.*

The change which occurs in the eye in the act of accommodation is illustrated in the following experiment: A wooden or pasteboard box (approximately 8 by 5 by 4 inches) is fitted with a piece of ground glass on one end and with a convex lens on the opposite end. This is a simple camera. Some object is now placed at such a distance that the lens forms an image of it on the ground glass, which is now in focus for the object. If, later, the object be moved nearer to the lens, the focus is changed; the image on the glass becomes blurred, and in order to make it distinct it will be found necessary to use a more convex lens or to change the length of the box.

Essentially the same change occurs in the eye in accommodating for near objects: *the lens must be made more convex*; and this, it will be remembered, involves work on the part of the muscle of accommodation (see page 284). We

can thus understand why, in general, it is too much near work, and especially near work necessitating very distinct vision, that tires the eye. The ideal condition of the eye, regarded merely as a camera, is that in which distant objects are focused on the retina when the muscle of accommodation is completely relaxed and the lens is thus flattened to its utmost by the elastic pull of the choroid coat (p. 285), for in this case the eye is rested by looking at distant objects, and works only when looking at near objects. Such an eye is known as an *emmetropic* eye (Fig. 102, *E*).

Unfortunately, not all eyes meet this requirement. The eyeball may be either too short or too long, so that, with the muscle of accommodation relaxed, the position of the perfect focus for distant objects is either before or behind the retina; such an eye does not see distant objects distinctly when it is at rest, because then the retinal image is blurred. To understand more fully the undesirable consequences of this condition, we must learn how convex lenses produce images of objects.

9. The action of a convex lens on rays of light. The rays of light diverging *from a single point* and entering a convex lens are bent so that all come together again in a point behind the lens, or, as it is said, are brought to a *focus*. At the focus the light is concentrated, since many rays there meet; but beyond, it progressively becomes dimmer as the distance is increased, because the rays, having crossed, are again divergent. This is shown in Fig. 100, as is also the fact that rays of light diverging from more distant objects come to a focus closer behind the lens than those diverging from nearer objects.

Now a lens forms an image of an object because all the rays of light from each point of the object are focused in corresponding points behind the lens. This is shown in Fig. 101, where all the rays diverging from 1 are focused

at 1′, all those from 2 at 2′, and those from intermediate points of the object at intermediate points of the image. It will be noted that the image formed by a lens is inverted; hence the picture received by the retina is upside down.

If the rays from each point meet in front of the retina and then diverge before reaching the retina, the retinal image is blurred; and the image is also blurred if the retina is so near the lens that the rays reaching it from each point have not yet come to a focus. The more convex the

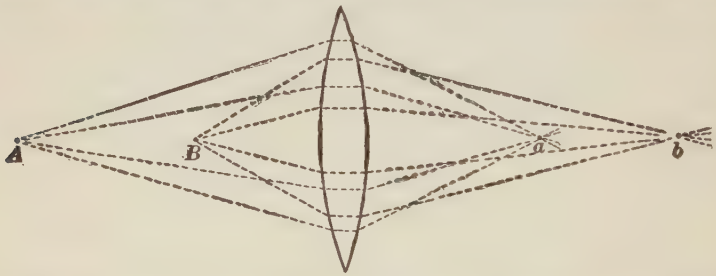


FIG. 100. Action of a convex lens in bringing to a focus the rays of light diverging from a single point

The rays from *A* are focused at *a*; those from *B*, at *b*

lens, the more will the rays of light be bent and the focus shortened; consequently we use the muscle of accommodation (which makes the lens more convex) to get clear images of near objects (see Fig. 100).

10. Emmetropia, myopia, hypermetropia, and presbyopia. In the *emmetropic* (normal) eye (Fig. 102, *E*) the distance between the retina and the lens is such that light from distant points comes to a focus on the retina without any active muscular accommodation; to see near objects the lens is made more convex.

When the retina is so far away from the lens that, with the muscle of accommodation completely relaxed and therefore the lens flattened to its utmost, light from distant points

comes to a focus in front of the retina, then the retinal image is blurred; it is impossible for such an eye to see distant objects clearly. To correct such vision it would be necessary to make the lens *still less* convex, and this the eye is unable to do. (Why?) Such an eye is known as *myopic*, or *nearsighted* (Fig. 102, *M*), and its defect must be corrected by the use of *concave* glasses, which produce the

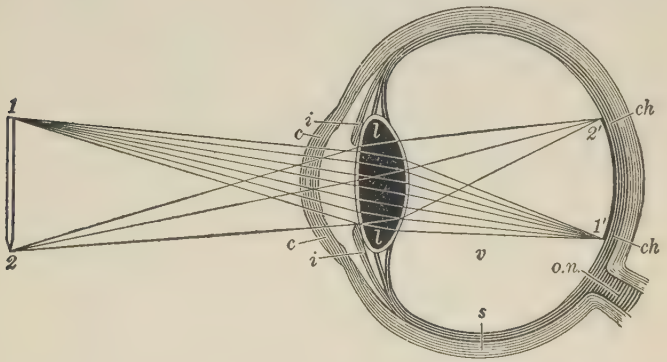


FIG. 101. Diagram showing the formation of an image on the retina

1, 2, the object; *1', 2'*, the image of the object; *c*, cornea; *i*, iris; *l*, lens; *v*, vitreous humor; *s*, sclerotic; *ch*, choroid; *o.n.*, optic nerve

same effect as if the lens were made flatter, and so throw the focus farther back. A myopic eye generally has clear sight for very near objects, because, as stated above, the nearer the object the farther back is the image formed.

On the other hand, the eyeball may be *hypermetropic*, that is, too short, fore and aft (Fig. 102, *H*), so that, when the ciliary muscle is relaxed, light from distant points has not yet been brought to a focus when it reaches the retina. Such an eye must accommodate not only for near but also for distant objects, and its muscle of accommodation can never rest so long as the eye is being used. Moreover, to see near objects, the ciliary muscle must work much harder

than in the normal eye, and it often happens that, even with its utmost effort, the rays are not sufficiently bent to focus them on the retina; so that a book, for example, must be held at arm's length to be read. Persons having such eyes form one class of those said to be *farsighted*, and their trouble can be corrected by the use of *convex* glasses.

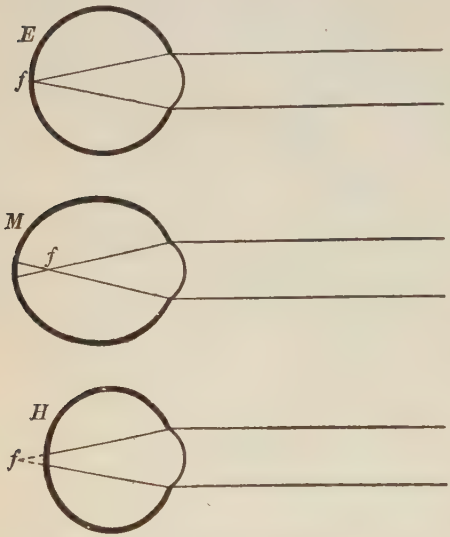


FIG. 102. The emmetropic (*E*), the myopic (*M*), and the hypermetropic (*H*) eye

Course of the rays of light from a distant point through these three types of eye, the muscle of accommodation being relaxed. (The rays diverging from a distant point would be practically parallel when entering the eye)

As old age comes on, changes occur in the lens; in consequence it becomes *presbyopic*, that is, it no longer becomes as convex as formerly in response to the action of the muscle of accommodation. This is *presbyopia*, from πρέσβυς, "old." Some, though not all, results of this condition resemble those of hypermetropia; but the two differ in cause. Hypermetropia is due to *shortness of eyeball*; presbyopia, to *failure of accommodation*, owing to hardening of the lens.

11. Astigmatism. We have thus far been dealing with those optical imperfections due to improper distance between the lens and the retina. Another and frequently more serious trouble, known as astigmatism, results when the curvature of the cornea (and sometimes of the lens) is not

perfectly regular; that is, when these surfaces are not segments of perfect spheres, but resemble in curvature the side of a lemon. In this case the rays of light from a point are not brought to a focus again in a point behind the lens; and remembering the importance of sharp focusing in securing distinct photographic as well as retinal images, the student will see that this defect must seriously interfere with clear vision. The optics of astigmatism are too complicated to be explained in an elementary work, but the defect reveals itself generally in an inability to see with equal clearness lines running in different directions. Thus some of the lines in Fig. 103 will seem sharply defined and black to an astigmatic person who is looking with one eye at the white center, and other lines will seem blurred and lighter in color.

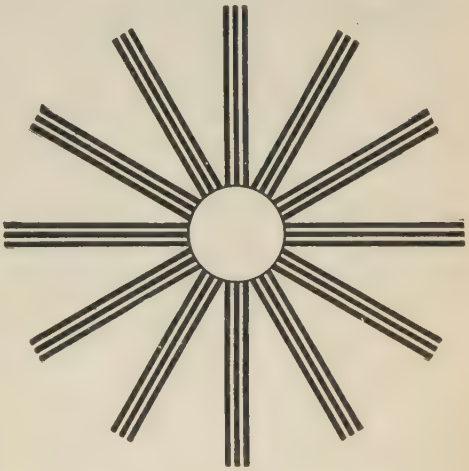


FIG. 103. A test for astigmatism

Astigmatism causes distress especially in reading, because printed letters are made up of small lines which run in different directions. The effort to see the printed page clearly is often severe, and results in headaches and other general disturbances of health, the true cause of which is often unsuspected. The trouble may usually be corrected by the use of so-called "cylindrical" glasses; that is, glasses which compensate the defects of curvature in lens and cornea.

12. Accommodation and near work. The defects of the eye as an optical instrument may usually be successfully corrected by the use of proper glasses, which should, generally speaking, be prescribed by a good oculist rather than by an optician. Glasses may be used for various reasons: for example, (1) convenience, where a person with a slight myopia wears them to see distant objects more clearly; (2) necessity, where myopia is so pronounced as to seriously interfere with the sight; and (3) comfort, where as a result of visual defects a person suffers from eyestrain, which is characterized by pain in the eyes, headache, nervousness, and other symptoms. A hypermetropic eye should always be provided with glasses, since otherwise its muscle of accommodation cannot be rested by looking at distant objects. But since it is near work which requires the greatest effort of accommodation, it is in reading, writing, drawing, sewing, and such activities that the eyestrain is apt to be greatest. As the demand for near work is constantly increasing in modern life, the complete correction of such defects becomes more and more necessary. Those whose occupations require long-continued use of the eyes should see to it that these precious organs are used only under the most favorable conditions, and that all strain is as far as possible relieved.

B. BINOCULAR VISION

We have previously been discussing vision from the standpoint of only one eye. Normally we view objects with our two eyes simultaneously. This renders it necessary that the images in both eyes be (1) focused exactly alike, (2) equal in brilliancy, and (3) formed at corresponding points (Fig. 104). The first two effects are obtained by coördinating the changes in the lenses and pupils, so that correspondence is

maintained; and the last by coördinating the actions of the muscles that move the balls, so that both eyes "look" in the same direction. Binocular vision is of value to us chiefly in forming our estimates, or judgments, of the distance, size, and shape of objects.

13. The movements of the eyeballs; the extrinsic muscles. The resting position of the eyeball may be considered as one in which the visual axes (Fig. 105) are parallel with one another and with the surface of the earth. This is the case when we look at a distant object across level ground. It is to the pupils that we must give particular attention; they are directed straight forward in the resting position described above. From this position they may be turned inward, upward, downward, and diagonally. These movements are effected by the action of six small muscles which are attached to the surface of each eyeball and extend back to adjacent bones of the skull. They are arranged in pairs, both members of each pair being of equal strength; for instance, the muscle for raising the pupil (rotating the ball upward), when at rest, is exactly balanced by the one for lowering the pupil (rotating the ball downward).

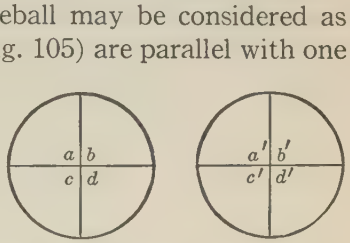


FIG. 104. Diagram explanatory of corresponding points, which are *a* and *a′*, *b* and *b′*, and so forth. In looking diagonally down toward the right the images are both formed at *a* and *a′*; diagonally up toward the left, at *d* and *d′*; and so forth

A change in the direction of one pupil must be accompanied by an identical change in the other (Fig. 105); that is, both move simultaneously upward, downward, to the right, to the left, inward, or outward (to the resting position). The purpose of these movements is to bring the images to corresponding points on the two retinas (Fig. 104). If this is not effected, one of three things will result: (1) two

images will be seen (diplopia), (2) only one eye will be used, the image in the other being mentally suppressed, or (3) eyestrain will develop, due to the endeavor to draw the pupil into normal position.

14. Ocular convergence. This is the act of turning the pupils inward on viewing near objects. With objects 20 feet or farther away the visual axes are parallel and the pupils are said to look straight ahead. This is designated "the

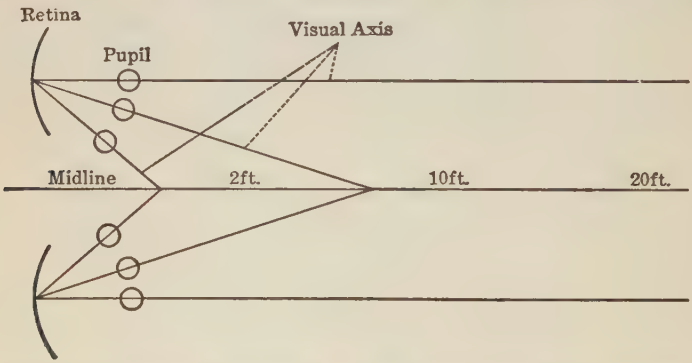


FIG. 105. Diagram demonstrating ocular convergence for objects at different distances

resting position," because all the extrinsic muscles are pulling with equal strength, this pull being due to tone only. For nearer objects, the pupils must be drawn inward. Normally both pupils are converged to the same degree, owing to the operation of a nervous coördinating mechanism. Should they fail to converge equally, in consequence of too much close work or for any other reason, the same symptoms noted in the preceding section will make their appearance. These may be corrected by prolonged rest of the eyes, by suitable exercises for the extrinsic muscles, and by wearing glasses; but a specialist should be consulted immediately if diplopia or other evidences of eyestrain develop.

15. Strabismus: crossed eyes. This is a condition in which one pupil is turned in a different direction from the other; for instance, the right is directed toward the object of interest, while the left is directed inward or outward. When the defect is marked, the afflicted persons are said to be *cross-eyed*; and since they cannot bring the images in the two eyes to corresponding points, they see effectually with only one eye. Where the disturbance is slight, there may be a diplopia when the eyes are at rest, which may be corrected by effort; but doing so will produce eyestrain for the reasons mentioned above.

Strabismus may be congenital, due to injury at or before birth, or it may follow diphtheria or infantile paralysis (p. 608), or be caused by abuse of the eyes resulting from microscopic work. As in other visual disturbances, a specialist should be consulted. He may direct suitable exercises, adjust glasses, or perform a surgical operation.

16. Accommodation and convergence involve nervous as well as muscular activity; the importance of sharp contrast. The work of the muscles of accommodation and convergence is controlled by the nervous system, and accurate adjustment of the eyes involves an unusually high degree of nervous coördination. The strain thus imposed may be lessened not only by the use of proper lenses and by giving the mechanisms of adjustment periods of rest (by looking for a time at distant objects), but also by choosing the most favorable conditions for near work. Perhaps the most important principle involved here is to secure the greatest possible contrast between the light and dark parts of objects at which we are looking. When the contrast is marked, the objects can be seen easily and recognized, even though the adjustments are not absolutely perfect. When, on the other hand, the contrast is not great, very accurate adjusting is necessary. Important means of securing the maximum contrast are the following:

1. *The avoidance of too little and of too great illumination of the object.* Let the student examine any printed page with different degrees of illumination. The contrast of white and black will be poor in dim and in very bright lights, and greatest with a certain moderate illumination. Hence reading in twilight or with sunlight falling directly on the page means greater eyestrain.

2. *The avoidance of a flickering light.* A steady light — one free from flicker — is of the highest importance for near work. In this respect a good kerosene lamp (student's lamp or Rochester burner) is perhaps the best of all lights for reading, provided the heat which it gives off is not too great. Electric lights are good if they are steady and are not too brilliant. Gaslight from an ordinary fishtail burner is one of the poorest lights for reading and sewing. The flicker of gaslight may, however, be largely avoided by the use of mantles.

3. *If the printed matter is not held steady,* the effort of accommodation becomes much more difficult. Consequently it is in general an added strain to read, and especially to read fine or poorly printed matter, on a street car or railroad train.

4. *The use of very fine type* should be reduced to a minimum. When such printed matter is held at the ordinary distance of thirteen inches from the eye, very accurate accommodation is needed, and this, we have just seen, involves nervous strain; if it is held closer to the eye (so as to make a larger image on the retina) the lens must be made much more convex to focus it, and this means excessive work on the part of the muscles of accommodation. This is very undesirable, and especially so in youth, since then the tissues of the eye are more plastic, and excessive strain of the muscles of accommodation, pulling as they do on the sclerotic and the choroid coats, may lead to permanent

deformity of the curved surfaces. The marked increase of myopia within the past forty or fifty years is generally explained in this way.

5. *Highly calendered paper objectionable.* Closely connected with the size of the type is the character of the paper on which it is printed. This should be as dull as possible in order to avoid the confusing effect of a glossy surface. The highly calendered paper in many books and serial publications, used because such paper lends itself more readily to the reproduction of pictures in half tone, is a sacrifice of hygienic considerations to the attractiveness of the illustrations.

17. Visual sensations. We have shown (p. 280) that the sensation of sight does not develop in the eye, but in the brain, as the result of nervous impulses sent thither over the fibers of the optic nerve from the retina. Just how the light falling upon the retina originates these impulses cannot be discussed here; suffice it to say that the character of the impulse differs according to the color of the light[1] which stimulates the retina; the lens focuses upon the retina a *flat, colored* picture of the objects at which it is directed, just as a photographic camera does. One part of the retina is thus stimulated by red and green light, and another part by blue and yellow light; still other areas are stimulated only by grays; and the different kinds of impulses started in the fibers of the optic nerve utimately, upon their arrival in the brain, excite in consciousness what we know as *visual sensations*. The sensations which we get from the retina are therefore primarily sensations of color.[1]

18. Visual judgments. When we look at an object we get more than mere sensations of color. The world does not appear to us as a flat surface of different colors, like the

[1] In this and the following paragraphs white, black, and gray are regarded as colors.

painter's canvas. When we look at the wall of a room we know that it is a flat surface, and when we look at a box we know that it has not only length and breadth but also thickness. If we were dependent entirely upon the retinal image for our idea of the box, it would look as flat as the wall; that it does not appear so is because we receive other information about the box than that which comes from the retina. We have to accommodate the lens differently for the near and the far edges, and we have learned by experience that this necessity indicates depth (thickness), or different distances of different parts of the object from our eyes. Again, we see the box with both eyes, and the images formed on the two retinas are not exactly the same. One eye sees more of one side, the other eye more of another side; and while we are not conscious of this fact, we have really learned by experience and by the actual handling of objects that this slight difference in sensations from the two eyes is produced only by solid objects. Again, when we look at any point on the near edge of a box the two eyes are converged by their muscles to a greater extent than when we look at a point on the far edge, and we have learned that these different pulls of muscles and positions of eyeballs indicate that the object is not flat, but has depth. The importance of binocular vision in the estimation of depth, or distance from the eye, is most strikingly illustrated by attempting, with one eye closed, to touch together the points of two pencils held horizontally in the hands and moved from side to side at arm's length.

Consequently when we look at anything we get a number of sensations; from the retina, sensations of color, of brightness and of shadow, and the position of colors with reference to one another; from the muscular efforts of accommodation and of convergence of the eyeballs, those sensations which reveal the property of depth in what we see. And

from all of these, fused together and interpreted in the light of experience, we construct a *visual judgment* of the nature of the object.

19. Optical illusions. That our vision is essentially the result of unconscious judgments is strikingly shown by the fact that these sometimes deceive us. Thus the parallel vertical lines in Fig. 106, when crossed by the oblique lines, seem to be inclined toward each other. The retinal images of the lines are parallel, and we falsely judge them inclined, this error of judgment arising from the presence of the oblique lines. In other words, our final idea of the lines does not correspond to their image on the retina.

FIG. 106. Optical illusions

Many other examples might be given, showing that our visual idea of the world around us is not a simple sensation or impression, but an unconscious inference, judgment, or conclusion built up from a number of simple sensations taken separately or blended together and compounded with the results of lifelong experience. In looking at a piece of fine silk or cloth we seldom stop to think that its tissue may be resolved into many simple component threads; and in quite the same way we fail to realize that even our quickly formed judgments of the size, distance, form, or color of objects are likewise tissues woven out of many threads, most of which we have been slowly and laboriously spinning since childhood's days in the hidden factory of individual experience.

II. The Ear and Sound

20. Sound and hearing. When a string of a violin, piano, or harp "sounds," one can observe that it is in rapid vibration; and the same thing is true of all sounding bodies. These vibrations are imparted to the air, water, or other

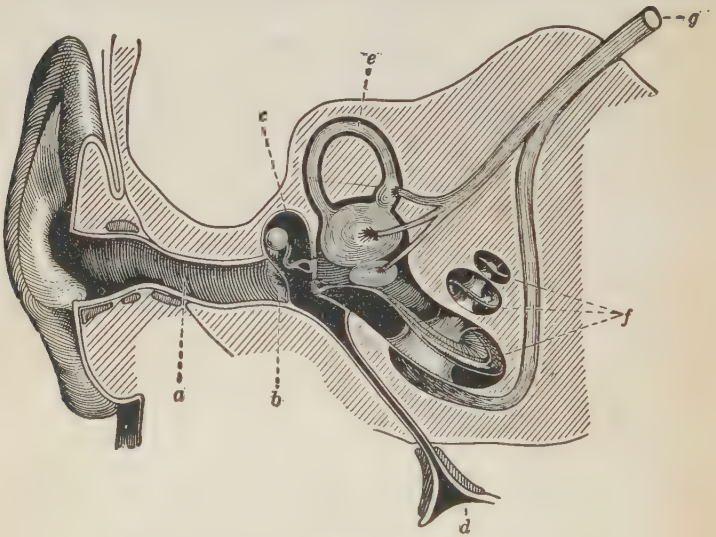


FIG. 107. Diagram of the ear

a, the auditory canal, leading to the tympanic membrane *b*; *c*, the tympanic cavity, communicating by the Eustachian tube with the pharynx *d*; *e*, semicircular canals; *f*, cochlea; *g*, auditory nerve

surrounding medium, and through this medium they are transmitted as waves of sound. It is these waves, or vibrations, which, on entering the ear, excite the sensation of sound. The more rapid the vibrations, the higher is the pitch of the note; and the greater their amplitude, the louder the sound.

The ear is an organ specially adapted to receive these vibrations and to transform them into nervous impulses. It

is subdivided by anatomists into the outer ear, the middle ear, and the inner ear.

21. The outer ear. The outer ear consists of the expanded *pinna* (or that part which we commonly call "the ear") and a tube along which the vibrations of sound pass inward to the *tympanic membrane*, or drum (Fig. 107). Glands along this canal secrete wax which guards the approach to the drum from dust and insects. It is a bad habit to pick at this wax, and especially to dig into the ear with an ear-spoon or any other instrument, for there is always danger of abrading the delicate lining of the canal or of perforating the drum. If trouble is suspected, a physician should be consulted.

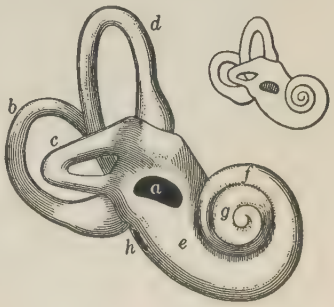


FIG. 108. The bony labyrinth, its actual size being shown in the smaller figure

b, *c*, *d*, the semicircular canals; *a*, the oval window, by means of which the vibrations of the stirrup bone are transmitted to the cochlea; *e*, *f*, *g*, the whorls of the cochlea. (Cf. Fig. 109)

22. The middle ear and the Eustachian tube. The tympanic membrane separates the outer from the middle ear, or *tympanic cavity*, a small cavity lying in the temporal bone of the skull and communicating with the throat or pharynx by means of the Eustachian tube (Fig. 107). Through this tube, the air in the middle ear is easily kept under the same pressure as that of the atmosphere without, hence the tympanic membrane is not normally bulged inward or outward by inequality of pressure on its two sides. The opening of the Eustachian tube into the pharynx is, however, closed except when one swallows, and hence swallowing often relieves the drum from unequal pressure of air in the middle ear.

The tympanic cavity also communicates with a network

of spaces, or *sinuses*, in the temporal bone (p. 301). Because of these connections of the middle ear with the throat, on the one hand, and with the temporal sinuses on the other, inflammatory processes in the nose and throat during a cold sometimes extend into the Eustachian tube, the tympanic cavity, and even into the temporal sinuses, causing serious trouble and occasionally deafness.

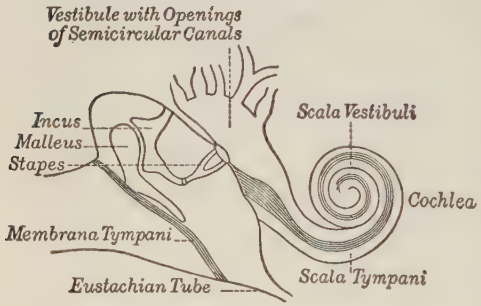


FIG. 109. Diagrammatic representation of the membranous labyrinth of the cochlea in relation to the structures shown in Figs. 107 and 108

The *scala vestibuli* and *scala tympani* are the two portions of the bony cochlea which inclose the membranous cochlea

Passing directly across the tympanic cavity, from the drum on its outer side to the cochlea on its inner side, is a chain of three very small bones, the *ear ossicles* (hammer, anvil, and stirrup). These bones are bound together and attached to the walls of the cavity by ligaments, and are so arranged that when sound waves set the tympanic membrane in vibration this motion is transmitted by the ossicles to a portion of the inner ear known as the *cochlea*.

23. The inner ear. The structures of the inner ear lie in the temporal bone, on the side of the tympanic cavity opposite the drum. They consist of a system of small bony spaces and tubes, the *bony labyrinth* (Fig. 108), within which lies a corresponding *membranous labyrinth* (Fig. 109). Forming part of the membranous labyrinth are very sensitive cells. Between these cells are the endings of the nerve fibers which connect the ear with the brain. The cells of

the inner ear are sensitive to the vibrations which have been transmitted from the drum by the ossicles, just as the retina is sensitive to light; and as the retina is the origin of the fibers of the optic nerve, so the inner ear is the origin of those of the auditory nerve.

III. Other Sensations

24. Taste and smell. The end organs of taste are small rounded eminences, or *papillæ*, on the upper surface of the tongue, and from these the fibers of the nerves of taste pass to the brain. The end organs of the nerve of smell are situated in the upper portion of the nasal cavity, and consist of delicate cells very sensitive to the presence of odors. Sensations of taste are frequently confounded with those of smell. An onion, for example, has little or no taste, as can be shown by placing a bit on the tongue when one is holding the breath; none of the flavor of the onion is perceived. On the other hand, *sour*, *sweet*, *bitter*, and *salt* are true sensations of taste. This unconscious blending of tastes with odors in forming our ideas of the nature of substances recalls the formation of visual judgments by the combination of retinal sensations with those aroused by the muscular act of converging the eyeballs.

25. Cutaneous sensations. The skin is the place of origin of at least three sensations — touch, cold, and warmth. These sensations are distinct, as is shown by the observation that on certain points of the skin some of them may be felt, but not others. This fact is usually interpreted to mean that each sensation has its own set of end organs and nerve fibers. Especially striking is the fact that warmth and cold are not felt by the same spot of skin, which seems to prove conclusively that they are separate sensations.

The afferent nerves of cold and warmth not only carry

into the brain those impulses which give rise to the corresponding sensations but also serve as one important means of stimulating the reflexes which help to regulate heat production and heat output (see Chapter XII).

26. The sense of position. The expression "the five senses" has become proverbial, and comes from the time when sight, hearing, taste, smell, and touch were the recognized special senses. Today, however, we must add to these not only warmth and cold but still others, most conspicuous among which is the sense of position. When the eyes are closed we are aware of the position of the various parts of the body. We know whether the arm is bent at the elbow or straight; whether the head is facing forward or is turned to one side or the other; whether the body is inclined forward, backward, or sideways; whether we are falling headforemost, or lying on the face, or moving upward or downward. While we are aware of these things partly from tactile sensations, there is conclusive evidence that afferent impulses from the muscles, tendons, and joints also play an important part in the result and that there must be still another device, as yet unexplained. For when one is blindfolded and lies flat on a revolving table which can be turned noiselessly in one direction or the other, the person experimented on can form fairly correct judgments as to the angle and direction through which the table is turned. Here there is no change of character either in the tactile impulses or in those from the muscles, tendons, and joints, for the person lies still and is only passively moved. It is believed that in this case the sensations in question come from the movements of the lymph

FIG. 110. A tactile corpuscle in one of the papillæ of the dermis; an end organ of the sense of touch

over sensory nerve endings in the inner ear. One part of this, the cochlea, is undoubtedly concerned with the sensation of sound; but another part, the three *semicircular canals*, are now believed to be end organs of this sense of position.

There are three of these canals (Fig. 108) on each side of the body, and they are arranged, approximately, one in each of the directions, forward-backward, right-left, and upward-downward. According to theory, when we incline or move the body forward, the lymph in the first mentioned of the canals moves backward and excites a nerve impulse which is transmitted to the brain, thus rendering us conscious of the direction in which we are moving. The second of the canals acts in the same way for lateral movements; and the third for ascent and descent. But the impulses from the semicircular canals do more than simply to render us conscious of position and direction of motion, for they are transmitted not only to the brain but also to the reflex centers. Through the latter the attitude, or posture, of the body is corrected and maintained; for instance, a forward inclination of the body is followed by a reflex contraction of the muscles of the back, which then draw the body toward the vertical position. Similarly, a person used to sleeping on his back, if he goes to sleep face downward, will reflexly turn over without awaking.

The impulses which make us aware of the position of the parts of our bodies also play a very important rôle in reflexly guiding our movements. Upon this we shall dwell at greater length in subsequent chapters (see especially Chapter XV).

27. Sensations of pain. Most organs of the body may also give rise to impulses which, on their arrival in the brain, cause sensations of pain. It is still, perhaps, an open question whether this sensation, like sight, smell, and hearing, is

aroused by its own mechanism of end organs and afferent nerves or is called forth by the excessive stimulation of the nerves of the other senses; but for the discussion of this question the reader must consult more advanced works on physiology.

Pain is a useful danger signal, since it effectively calls attention to abnormal conditions and incites us to the adoption of active remedial measures. Remedies, however, should not be confined to the abolition of unpleasant sensations, but should be directed to the removal of their cause. A toothache from a decaying tooth may often be stopped, for a time at least, by the use of chloroform or some other anæsthetic drug, but the drug only stops the pain; it does not check the progress of decay or repair the damage. Again, a bronchial cough may be unpleasant and even painful, but we should not rest content with the use of some drug or cough medicine which merely lessens the irritability of the inflamed surface of the air passages, and so, perhaps, stops the cough without curing the disease.

Pain is a warning that some abnormal condition needs attention. Sometimes that attention may be supplied by the sufferer himself, or by his friends, but often skilled medical advice is needed. Too frequently, for the sake of economy or from feelings of modesty, or even because of an unwillingness to acknowledge illness either to the world or to one's self, the mistake is made of postponing the visit to the physician, the patient meanwhile bearing discomfort and perhaps actual suffering in the hope that he will soon be better and that the trouble will "cure itself." Sometimes, of course, it does cure itself; but sometimes it does not; and remediable disease has too frequently been allowed to run on in this way until some vital spot was attacked or the trouble became too grave for medical skill to overcome. Many diseases, like a fire, may be extinguished

at the start, but, if not attended to, grow rapidly into a conflagration beyond control. Pain is one of the most trustworthy warnings that attention to the mechanism itself or to our operation of it is necessary; and we have no right, either for our own sake or that of our friends, to neglect its warnings. Although there are times when it is an act of heroism to endure suffering and to keep the knowledge of it to one's self, there are other times when to do this is not only foolish but wrong.

28. Hunger and thirst. No account of the physiology of sensations would be complete without some reference to those very common experiences of life, hunger and thirst. We have already spoken of them as sensations which are referred to the body and never to external objects, thirst usually being referred to the mouth and throat, and hunger frequently to the stomach; but hunger and even thirst may sometimes affect us as sensations coming from the body as a whole, in which case they are usually indistinguishable from certain forms of general fatigue.

Hunger is excited by automatic rhythmic contractions of the musculature of the cardiac end of the stomach. The stomach, like the heart, executes rhythmic contractions, and we may speak of the "beat" of the stomach just as we speak of the beat of the heart, although the stomach contractions are much slower than those of the heart. When food is in the stomach, these contractions or beats are inhibited in the cardiac end or else are reduced to very insignificant proportions; we have then the inactive condition of this portion of the stomach described in Chapter VIII; but when the cardiac pouch is again empty, the inhibiting check is removed and the automatic beats become quite powerful. These contractions start impulses up the sensory nerves of the stomach, and these impulses excite in our consciousness sensations of hunger. Often the beats occur

in rhythmic periods, a group of strong contractions alternating with groups of weak contractions or even total quiescence. In this case we have the "griping" hunger pangs coincident with the strong contractions. In certain abnormal conditions the presence of food in the stomach fails to exert its inhibiting effect and we have a continual "gnawing" hunger.

Thirst is aroused by dryness of the mouth and throat, caused probably by a reduction of the amount of water in the cells and tissues of this region.

Hunger and thirst are definite sensations, as truly adapted to guide us in the regulation of eating as sight is adapted to picture to us the world in which we live. So long as the body is normally occupied and healthy they may usually be trusted; but there are abnormal conditions of sedentary life, in the midst of a superabundance of tempting food, when they become less trustworthy, and in some forms of dyspepsia the sensation of hunger is never absent, no matter how often one eats. In such cases the very effort to satisfy hunger only aggravates disease. Conditions of this sort should not prevail if proper attention is paid to the general hygienic conduct of life. Broadly speaking, appetites, like fire and dynamite, are good servants but bad masters.

CHAPTER XV

THE CENTRAL NERVOUS SYSTEM

The central nervous system may be referred to as "the ruler of the body," for it is the seat of the mind and through its activities all parts of the body are brought to work effectively together. It is commonly divided into two portions, the brain and the spinal cord. These, with their numerous subdivisions, and nerves connecting them with all parts of the body, constitute the cerebrospinal system.

In the preceding chapter we have repeatedly emphasized the fact that sensations of all kinds are developed in the brain from nervous impulses coming from the sense organs, and in a previous chapter (VII) we have seen that without reaching the brain, or at least without affecting consciousness, these afferent impulses may give rise to reflex action. A reflex action or a conscious sensation, or both a reflex action and a conscious sensation, may therefore result from the entrance of a nervous impulse into the central nervous system, and we have now to inquire what is known of the mechanism by which these results are brought about.

I. The Anatomy of the Central Nervous System

1. Fundamental structure of the central nervous system; the brain and spinal cord of a frog. The human spinal cord and brain are so complicated that it is best to study first the nervous system of a simple vertebrate, like the frog, for the fundamental plan of structure is the same in both. The spinal cord is a relatively thick-walled tube, the walls of

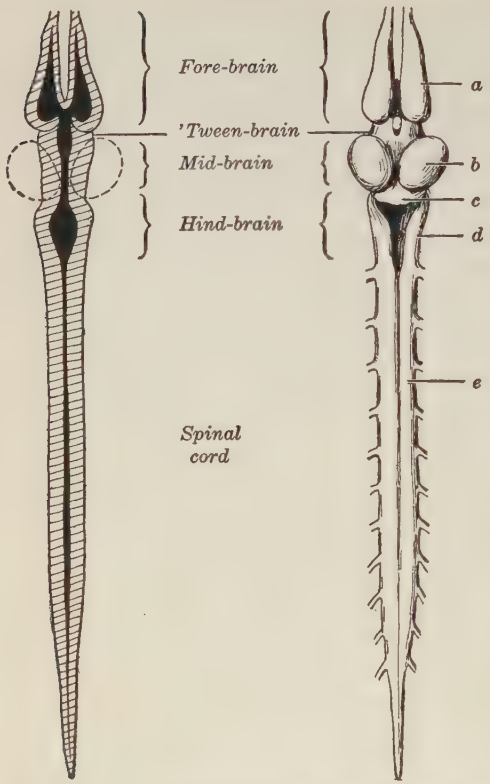


FIG. 111. The brain and spinal cord of the frog

On the left is a longitudinal, right-to-left section, showing the central canal of the spinal cord and the ventricles of the brain; on the right the dorsal view of the brain and cord. *a*, cerebral hemispheres; *b*, optic lobes; *c*, cerebellum; *d*, bulb; *e*, spinal cord

which are composed of white and gray matter, the minute bore, or lumen, of the tube, known as the *central canal*, being full of fluid. The arrangement in the brain is similar, but here the central space filled with fluid is no longer a small tube of approximately even bore, but consists for the greater part of irregular cavities, the *ventricles* of the brain, while the walls consist of masses of gray and white matter varying in size, shape, thickness, and relation to each other.

Fig. 111 will assist the student in understanding this plan of structure. Anteriorly the spinal cord is continued in the *bulb*,[1] whose central cavity is the *fourth ventricle*. Part of the dorsal wall of this ventricle forms the *cerebellum*, which

[1] The older term for the bulb is the *medulla oblongata*, to distinguish it from the *medulla spinalis*, or spinal cord.

in the frog is only slightly developed, but which in higher vertebrates (birds and mammals) becomes a large and conspicuous organ. Anteriorly the fourth ventricle is connected with the *third ventricle* by a tube, the *aqueduct of Sylvius*. The thick walls of this aqueduct contain various masses of gray matter whose names need not detain us; the walls of the third ventricle are similarly composed of large masses of gray matter scattered among the fibers of the white

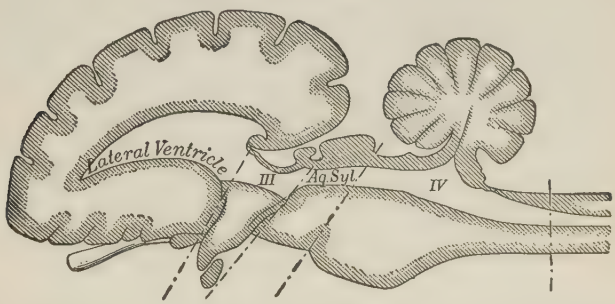
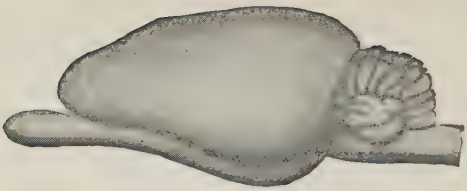


FIG. 112. Diagrammatic median longitudinal section of a mammalian brain. After Edinger

For convenience the cerebrum, with its lateral ventricle, is represented as a single organ in the median plane instead of two hemispheres on either side of this plane and each with its own lateral ventricle. The division into fore-brain, 'tween-brain, mid-brain, and hind-brain is marked by the broken lines

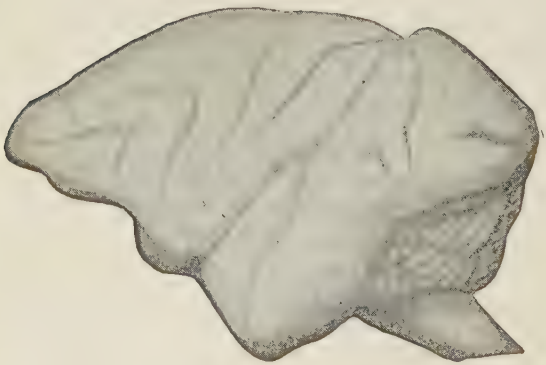
matter. Still farther forward two openings from the third ventricle, one on the right and one on the left side, lead into the large *lateral ventricles*, the nervous tissue of whose walls is the *cerebrum*, or the *cerebral hemispheres*. It is convenient to divide the brain into the *fore-brain*, surrounding the lateral ventricles; the *'tween-brain*, surrounding the third ventricle; the *mid-brain*, surrounding the aqueduct of Sylvius; and the *hind-brain*, surrounding the fourth ventricle (Fig. 112).

2. The brain of a mammal is built on the same fundamental plan as that of the frog, and differs from it mainly in the greater number of neurones and in the complexity of



Rabbit

Cat



Monkey

FIG. 113. Side view of the brains of rabbit, cat, and monkey

their connections with one another. This results in great thickening of the ventricular walls and the formation of a very complicated anatomical structure. Mammals are especially characterized by an enormous development of the cerebral hemispheres, which in man grow to such proportions upward and backward as to overhang and completely cover the other structures on the dorsal side. But even these large masses of nervous tissue, no less than the smaller cerebrum of the frog, are composed entirely of the gray and white matter forming the walls of the lateral ventricles.

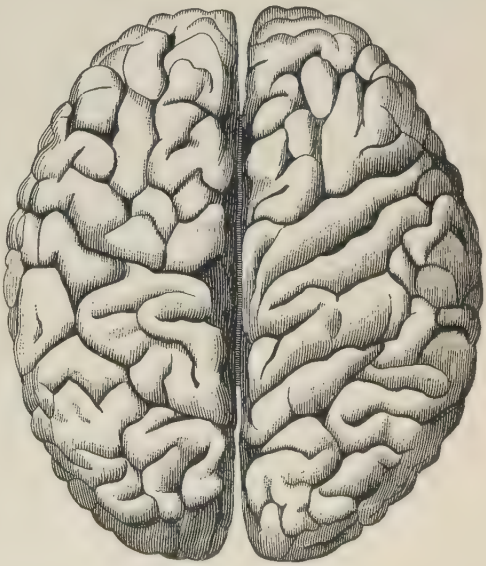


FIG. 114. The human brain viewed from above
The cerebral hemispheres completely cover the rest of the brain

By comparing the brain of the frog (Fig. 111) with brains of the rabbit, cat, and monkey (Fig. 113), and finally with the human brain (Figs. 114, 115, 116), a fairly good idea may be had of the increasing complexity of the brain as we pass from the lower to the higher animals. Especially noteworthy is the greater relative prominence of the cerebrum. In the frog this organ is small and inconspicuous; in the rabbit it is much larger, but its surface is smooth; in the cat there is a further increase in size, and the surface is thrown into folds, or *convolutions*; and this

increase in size and surface folding — carried yet further in the monkey — reaches its highest development in the human brain.

3. The cranial nerves. Nerves enter and leave the 'tween-brain, mid-brain, and hind-brain somewhat as they enter and leave the spinal cord; and although their separation

FIG. 115. Median longitudinal section of the human brain

a, b, c, d, l, convolutions of the median surface of the cerebrum; *e, f,* the cerebellum, showing in the plane of section the inner white matter and the outer gray matter; *h,* the *pons Varolii*; *k,* the bulb

into dorsal and ventral roots is not obvious, the neurones to which their nerve fibers belong are in all respects analogous to the neurones of the spinal nerves. These are known as the cranial nerves. They connect the brain with various other organs, chiefly with those situated in the head but also with some of those in the neck, thorax, and abdomen. There are twelve pairs of them; several of these are composed only of sensory or only of motor fibers, but most of them, like

the spinal nerves, are composed of both sensory and motor fibers. Each pair is designated by a Roman numeral as well as by a specific name, as follows: I, *olfactory*; II, *optic*;

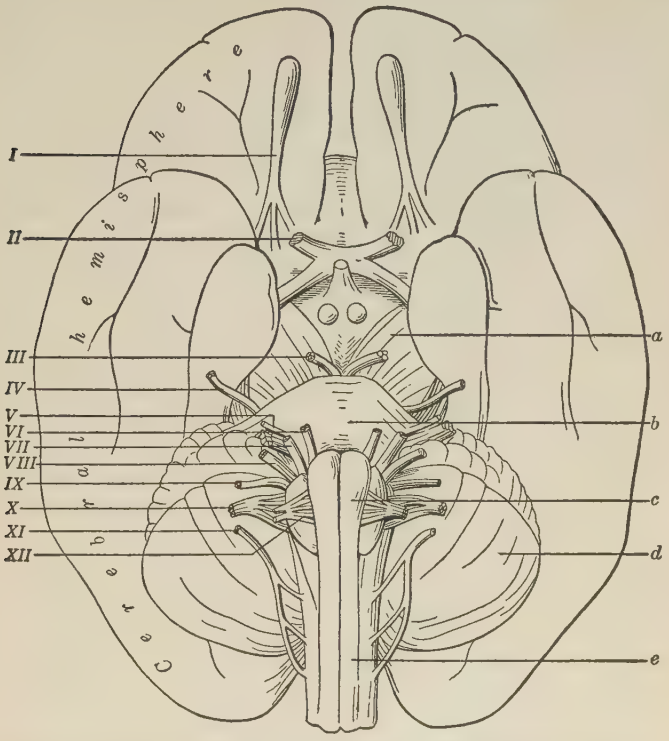


FIG. 116. The base of the human brain, showing the cranial nerves. (Roman numerals)

a, the *crus cerebri*, composed largely of nerve fibers which connect the hind-brain with the 'tween-brain and fore-brain; *b*, the *pons Varolii*, the anterior floor of the fourth ventricle, connected laterally with the cerebellum; *c*, the bulb; *d*, the cerebellum; *e*, the spinal cord

III, *oculomotor*; IV, *trochlear*; V, *trigeminal*; VI, *abducent*; VII, *facial*; VIII, *auditory*; IX, *glossopharyngeal*; X, *vagus*; XI, *spinal accessory*; and XII, *hypoglossal*. Their functions

are too complicated to be studied in detail here. Some of these nerves serve as the paths of reflexes (for example, a wink is a reflex from the optic nerve or from the trigeminal nerve to the facial nerve), and their relation to the cells of the cerebrum and other higher portions of the brain is essentially the same as that of the spinal nerves. Fig. 116 gives the points of entrance or exit of these nerves, in the case of the human brain.

The sensations and the motor and secretory activities effected through the cranial nerves may be summarized as follows:

Smelling. The first pair of cranial nerves (I) conveys impulses from the olfactory mucous membranes of the nose.

Seeing. The second pair (II) transmits the stimuli aroused in the retinas by the image of the object; the third (III), the fourth (IV), and the sixth pair (VI) so direct the eyeballs that the image is formed on the most sensitive parts of the retinas (the foveas); and the third pair (III) focuses the lenses and regulates the size of the pupils, so as to produce sharply defined images.

Hearing. The eighth pair (VIII) conducts the impulses created in the cochleas by sound waves; and the fifth (V) and the seventh pair (VII) adjust the tension of the tympanic membranes and the movements of the auditory ossicles, so as to effect optimal transmission from the auditory canals to the cochleas.

Tasting. The fifth (V), the seventh (VII), and the ninth pair (IX) connect the taste, or gustatory, organs with the brain.

Common sensations (touch, pain, and temperature). The fifth pair (V) transmits these common sensations from the face, eyes, nostrils, mouth, and teeth.

Equilibrium. A branch of the eighth pair (VIII) conveys impulses from the vestibules and semicircular canals of the inner ear.

Mastication. The fifth pair (V) conducts impulses to the muscles of mastication (chewing); and the fifth (V) and the twelfth pair (XII) bring about, respectively, compression of the cheek and elevation of the tongue, in order that food may be kept between the teeth during the process of chewing.

Facial expression. The seventh pair (VII) is excitatory to the muscles concerned in smiling, laughing, crying, and frowning.

Talking. The seventh pair (VII) stimulates the muscles of the lips; the tenth (X), those of the jaws and cheeks; and the ninth (IX), the tenth

(X), the eleventh (XI), and the twelfth pair (XII), those of the throat, larynx, and tongue.

Secretions. The seventh (VII) and the ninth pair (IX) supply secretory nerves to the salivary glands; the tenth (X), to the stomach and pancreas; and the fifth (V), to the lachrymal glands.

Regulatory effects. The tenth pair (X) transmits stimuli which retard the action of the heart but increase the peristaltic contractions of the stomach and of the greater portion of the intestines.

4. Histological structure of the brain. Microscopic study of the brain shows an aggregation of neurones similar to that seen in the spinal cord. These neurones differ greatly in shape (see Chapter VII, p. 91), in the number of their dendrites, and in the abundance of their connections with other neurones. The regular arrangement found in the cord, of central gray matter surrounded by white matter, is wanting; instead, masses of gray matter occur here and there among the bundles of nerve fibers of which the white matter is composed. In the cerebrum and cerebellum the external surface consists of gray matter and

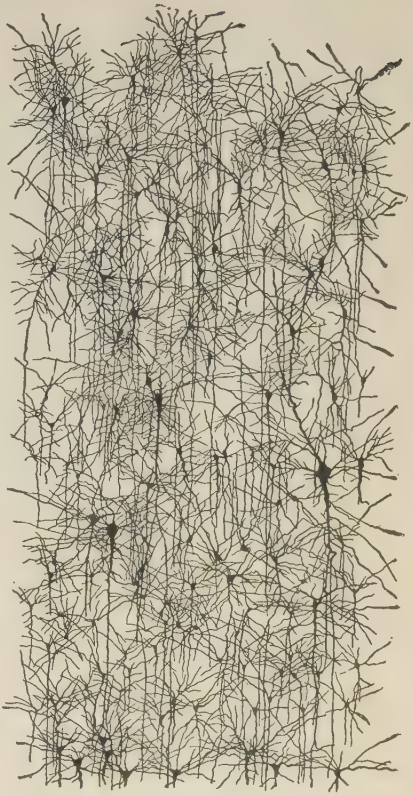


FIG. 117. A portion of the gray matter (cortex) of the cerebrum (highly magnified). After Kölliker

Note the large number of dendrites. The axons are the fibers of uniform diameter running lengthwise of the drawing. One of these cells is shown in Fig. 43, *D*

is known as the *cortex* of the cerebrum and cerebellum respectively. These cortical structures form the most complicated system of nervous tissue in the body, and the cerebral cortex is intimately concerned with the highest functions of the brain. (See Figs. 117, 118, and 119.)

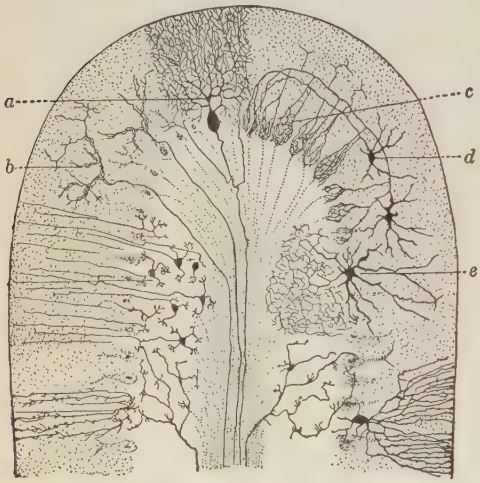


FIG. 118. Transverse section of a convolution of the cerebellum. After Ramon y Cajal

The figure represents only a few of each kind of nerve cells and nerve endings. *a*, *d*, *e*, cells; *b*, *c*, nerve endings

The illustrations give some idea of the variety and complexity of the neurones of the brain. But however different, at first sight, the brain may seem from the spinal cord, the anatomical plan of organization is similar in both; the brain as well as the cord does its work because the connections of its neurones with one another bring about coördinated action. The secret of the structure of the brain, as of the cord, lies in the nature of the connections of its units, the neurones, one with another.

5. The spinal cord of the mammal. The structure of the spinal cord is in general similar in all animals, though more complex in the higher types. Its description and nervous connections were given in Chapter VII, which should be reviewed at this time.

II. The Physiology of the Central Nervous System

Whenever through accident, disease, or otherwise, some portion of the nervous system is destroyed, functions dependent upon it are no longer performed, or at least are not performed normally. A very large number of observations have been made upon both animals and men in this condition, and these have made it possible for us to obtain some idea of the part played in normal life by each part of the brain and cord. We shall attempt here to sketch only a few of the more important outlines of the picture, which the reader may complete by more extensive study of physiology and psychology.

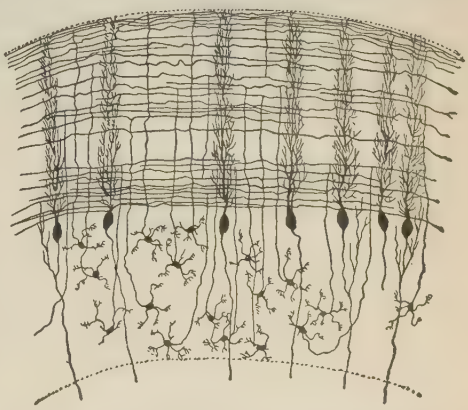


Fig. 119. Section of the cortex of the cerebellum (at right angles to that shown in Fig. 118). After Ramon y Cajal

We shall choose for study the case of a single animal, the frog, the anatomical structure of whose brain has been given in this chapter. The inferences which we shall draw from the behavior of the frog are, however, in general applicable to other vertebrate animals.

We shall therefore study (1) the behavior of a frog with only the spinal cord intact, its brain having been destroyed; (2) the behavior of a frog with spinal cord and hind-brain intact, but destitute of mid-brain, 'tween-brain, and fore-brain; (3) the behavior of a frog with spinal cord, hind-brain, mid-brain, and 'tween-brain, but destitute of the fore-brain.

The behavior of these incomplete animals will each be compared with that of a normal frog, which, of course, possesses a complete nervous system.

6. The behavior of a brainless frog. In this case we take a frog which possesses of its central nervous system only the spinal cord. Such a frog can carry out only reflex actions of a comparatively simple character. It lies flat upon its belly and, like the normal frog, bends its hind legs under its flank, but does not sit erect by supporting the head and upper trunk on the forelegs. There are no respiratory movements; the vaso-constrictor tone of the blood vessels is impaired or absent, as are also many other of the most important reflexes.

But if one leg be pulled gently backward, the animal will bend it again to its normal position under the body. If the toe be pinched, the leg will suddenly be drawn away; and if the skin of the flank be irritated by a bit of filter paper moistened with acid, the paper will be kicked off by the leg of the same side.

These are all purposeful[1] and coördinated actions, and make upon the inexperienced observer the impression that the frog is aware of the stimulus and acts intelligently. But the mere fact that an act is purposeful and coördinated does not show that it is a conscious act; our movements of respiration, winking, coughing, and sneezing are purposeful and coördinated, but we know well enough that they, as well as more complicated actions, may and often do occur in the complete absence of consciousness. We must learn not to make the mistake of regarding an action as conscious merely because "it looks so" or is purposeful and more or less highly coördinated.

[1] The word "purposeful" is used here in the same sense as in Chapter VII (p. 97) and does not include *conscious* purpose in its meaning. We shall see that conscious purpose involves the coöperation of the cerebrum.

The spinal cord alone, then, and without the help of the brain, is capable of maintaining a small part of the normal posture of the resting frog and also of executing some of the simple reflexes, especially those involving movements of the hind legs, but it does not seem to be capable of originating actions or of performing any except reflex actions.

7. The behavior of a frog with spinal cord and hind-brain only. In this case there is no new feature in the maintenance of posture; the frog lies on its belly and executes the same reflexes as before. The respiratory movements, however, go on in a normal manner; the vasomotor tone of the arteries is maintained, most vasomotor reflexes may be produced with ease, and the heart may be reflexly inhibited. As compared with the brainless frog, the number of actions which the animal can execute is increased, and the reflex movements become somewhat more complicated; but the differences are slight as compared with those seen in the animal which has the 'tween-brain and mid-brain in addition to the hind-brain and cord.

8. The behavior of a frog with spinal cord, hind-brain, mid-brain, and 'tween-brain. In this case we take a frog with the entire nervous system exclusive of the fore-brain, or cerebrum. The following points are especially noteworthy: (1) the sitting posture maintained at rest; (2) balancing movements; and (3) more complicated movements of locomotion.

1. Such a frog, unlike those already described, *sits erect* exactly like a normal frog; and this fact shows that complete maintenance of the normal posture requires the coöperation of higher portions of the nervous system than the hind-brain and spinal cord, but does not involve the coöperation of the fore-brain.

2. If the frog be placed on a rectangular block of wood, and the block slowly turned so that the frog tends to slip

off backwards, it will crawl up and over the descending edge, keeping itself perfectly balanced. By continuing to turn the block the frog can be made to creep around it almost indefinitely. Thus it not only maintains the erect position but also *corrects loss of equilibrium* by appropriate balancing movements.

3. If the frog be stroked upon its belly, it will croak; if its lips be touched with a blunt pin, it will brush the pin away with its forefoot. Most important of all, if it be thrown into the water, it will swim; and when it reaches a solid object it will crawl out upon it and come to rest. In short, the animal will carry out almost any movement of which a normal frog is capable, *provided the proper stimulus is applied*; but without this it will do nothing, though capable of doing so much.

The facts thus far brought forward show that the neurones of the 'tween-brain, mid-brain, and hind-brain and of the spinal cord constitute nervous mechanisms which can maintain the normal posture, correct loss of balance, and even carry out the usual acts of locomotion. The more of the nervous system which the animal retains, the more complicated are the movements, as we should expect when we remember the increase in the number of neurones and the greater complexity of coördination thereby rendered possible.

9. Comparison with the normal frog. The behavior of a frog lacking only the fore-brain, or cerebrum, differs from that of a normal frog in two most significant respects. In the first place, the animal rarely makes any movement without obvious external stimulation; if protected from drying, it will often sit motionless for days, or even weeks. Such is not the conduct of an animal which is aware of what is going on around it or of its own sensations or feelings, that is, of a conscious animal. In the second place, the frog shows the most remarkable regularity and persistency in

making repeatedly the same response to the same stimulus; if its lips be touched thirty times with a blunt needle, it will brush at the offending object every time in the same way with the same forefoot. We should certainly not expect a conscious animal to do this; for, after trying one plan of action a few times, it would realize that its efforts were unavailing, and would try something else, such as jumping away. This same peculiarity is met with in all animals deprived of the cerebrum. They act like mere complicated and faithful machines; they do not act as if they were thoughtful, original, or wise.

Especially striking is the avoidance of objects during locomotion. This fact looks at first sight as if the animal were aware of the presence of the obstacle in its path; but a dog without a cerebrum, even when it has been without food for a day or more, will go to one side of a piece of meat and pass it by. He acts as if *unaware of the nature of the object*, of its use as food, and so forth. The image of the piece of meat formed on his retina seems to generate nervous impulses which pass to the brain by way of the optic nerve and reflexly guide the movements of the dog, but these impulses do not inform the animal of the nature of the object, and we have no reason to believe that the dog is aware of the existence of the meat.

When we consider our own experience we find that we too, as we walk along a crowded street, avoid objects, not only without noticing them but without even being aware of their presence. Here again the afferent impulses from the retina pass to the nervous system and *reflexly* guide our walking without affecting consciousness at all. And the wonderful feats of somnambulism, where the "eyes are open" but "their sense is shut," where the sleeper maintains his balance and avoids stumbling in situations where he would almost inevitably fall if he were aware of his

surroundings, show how perfect is this very complicated mechanism of locomotion, which seems to be complete even in the absence of the cerebrum.

We are, indeed, so accustomed to regard our actions as volitional and conscious that we rarely consider the large part which reflexes from the eye, the ear, the skin, the muscles, and the joints play in guiding them. We will to do a certain thing, to walk to a certain point, for example; perhaps the first step is a volitional act, but subsequent steps, the suiting of these steps to slight unevenness of the path, the avoidance of many obstacles, the maintenance of the balance of the body as a whole, — for we walk not only with the legs but with the entire body, — all these things take place apart from any exercise of the will and, for the greater part, in the entire absence of consciousness, although consciousness may, of course, at any time intervene. Reflex actions thus play a most important part even in the execution of those movements which we think of as distinctly conscious acts.

10. Connections of the cerebrum with lower portions of the nervous system; "the way out." Granting that the nervous events at the basis of consciousness occur within the cerebrum, how do these events influence the muscles, the glands, and other organs which do the bidding of the will? What is the way out from this seat of consciousness? This path has already been referred to in Chapter VII (p. 99). Cells in the gray matter of the cerebrum give off axons which pass downward to the structures of the 'tween-brain, mid-brain, hind-brain and the white matter of the spinal cord. These axons give off along their course collaterals which end in arborizations around nerve cells in the lower portions of the nervous system (that is, below the cerebral hemispheres and, by bringing groups of these cells into coördinated activity, produce definite volitional movements. The student should

review carefully in this connection what has already been said with reference to these neurones (see diagram opposite page 328).

11. Connections of the cerebrum with lower portions of the nervous system; "the way in." The fact that afferent impulses from our sense organs of sight, hearing, and so forth may affect consciousness indicates that there must be some connection between afferent neurones and the cerebral hemispheres, since only when the latter are present does a nervous impulse produce a conscious sensation. The connection is not, however, so direct as in the case of efferent impulses. The neurones of the dorsal roots of the spinal nerves may be traced as far up as the bulb, but no farther; from this point the impulse can find its way to the cerebrum only when relayed by new neurones, and of these it would seem that there are several. These relations are indicated in the diagram opposite page 328, where the efferent neurones are represented in black, and the afferent in red.

This diagram brings out the fact of the increasing complexity of reflexes as we proceed to the more anterior portions of the nervous system. In the spinal cord the collaterals of the afferent neurone act upon efferent neurones; in the structures of the mid-brain and the 'tween-brain the afferent pathways make connection with more and more complicated and extensive systems of these efferent neurones. Finally, in the cerebrum the highest of all these connections is made; here take place those events of whose nature we have thus far been quite unable to form any conception, but which play some part in the genesis of conscious sensations and in the closely related dispatch of volitional impulses. We can now understand why it is that removing this highest portion of the nervous system leaves unimpaired not only the simpler reflexes but even the more complicated reflexes of locomotion, of swimming, of flight, and so forth.

12. The nervous factors in locomotion; automatic and reflex elements. It is clear from the considerations given above that walking, running, and other forms of locomotion are essentially nonvolitional acts, and it is also clear that there must be a nervous mechanism capable of carrying them out without the aid of, and even in the complete absence of, consciousness. What is the nature of this mechanism? In answer we can only suggest an explanation.

In the first place, walking obviously involves alternate steps, or forward thrusts of the body by the two legs; that is, while one leg is pushing the body forward by straightening at hip, knee, and ankle joints, the other leg is bending at these joints, the flexion of each leg at the hip joint bringing it forward in preparation for its next forward thrust. In each leg, then, we have an alternation of "forward swing" (flexion at hip, knee, and ankle) and of "extensor thrust" (extension at hip, knee, and ankle). In the same leg the flexors of the hip, knee, and ankle obviously contract at approximately the same time, and the extensors at the three joints similarly act together; furthermore, the extensor action in one leg is simultaneous with the flexor action in the opposite leg. These actions may be represented in diagram as follows:

Right leg	Hip	Ex.	Fl.	Ex.	Fl.	Vertical columns represent simultaneous actions at the eight joints
	Knee	Ex.	Fl.	Ex.	Fl.	
	Ankle	Ex.	Fl.	Ex.	Fl.	
	Toes[1]	Fl.	Ex.	Fl.	Ex.	
Left leg	Hip	Fl.	Ex.	Fl.	Ex.	
	Knee	Fl.	Ex.	Fl.	Ex.	
	Ankle	Fl.	Ex.	Fl.	Ex.	
	Toes	Ex.	Fl.	Ex.	Fl.	

[1] Flexion of the toes in each leg occurs simultaneously with extension at the other three joints, and vice versa. With most people, owing to the use of improperly shaped shoes, the toes are little used in walking. See Chapter XXIV, on the hygiene of the feet.

Now it has been shown that in an animal made unconscious by ether anæsthesia, and in which no afferent impulses may enter the cord or brain, — because of the depth of anæsthesia or even because of cutting the dorsal nerve roots, — similar movements of the hind legs spontaneously arise and may be kept up for long periods of time. Evidently there is *a mechanism located entirely within the central nervous system*, which by itself, independently of any afferent stimulation from the outside, either conscious or unconscious, *can automatically carry out a large part of the act of locomotion.* Locomotion becomes fundamentally the act of an automatic mechanism and is comparable to the alternate automatic contractions of inspiration and expiration.

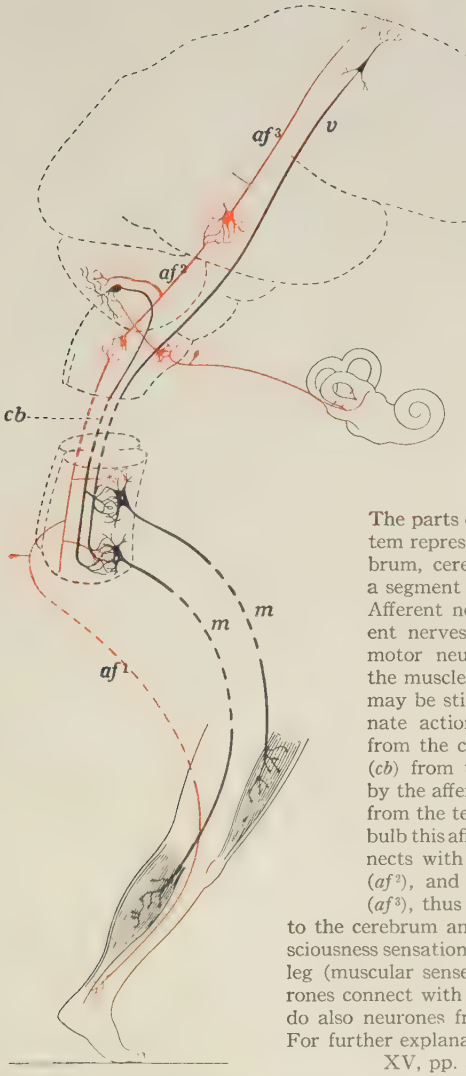
The parallel between the automatism of respiration and the automatism of locomotion becomes still more striking when we find in both cases that afferent impulses do actually intervene to guide and so make more exact and efficient the fundamental automatic movements. Thus we know that afferent impulses started by the expansion of the lungs during inspiration check the inspiratory effort then in progress and so bring on the next expiration sooner than it would automatically occur. Similarly, the pressure upon the sole of the foot as it touches the ground guides reflexly and probably strengthens the automatic extensor thrust; and many other reflexes through the cord are known to serve similar functions.

To sum up, then: The action of the legs in locomotion seems to be fundamentally an automatic action, but these automatic movements are guided by afferent impulses which stream in from skin, muscles, and joints as the act progresses. Just as we can volitionally hold the breath, so we can volitionally start or stop walking; or just as we can volitionally change the depth and rhythm of respiration, so we can volitionally change the pace or length of stride;

or just as a dash of cold water on the skin or the presence of an irrespirable gas reflexly changes the character of the breathing movements, so unevenness of the path or visual impulses from an object in the way change the character of the locomotion. In all cases reflex and volitional interference acts on a fundamental automatic nervous mechanism.

13. The maintenance of balance and the regulation of muscular tone. Walking, however, involves more than the action of the neuromuscular mechanisms of the legs; for here, as well as in complicated volitional actions, the balance of the body must be preserved. For this reason we swing the arms and execute ever-changing contractions of the muscles of the trunk. Moreover, a proper state of tonic contraction in each muscle is necessary to the proper execution not only of the act of walking but of other acts as well, whether these are volitional or nonvolitional (see diagram opposite page 328). Into the mechanism of this wonderfully perfect function of the body we cannot go within the limits of the present book; but there is good ground for thinking that, at least in the mammals, the cerebellum is a very important and probably the all-important organ in effecting the coördinations with which we are concerned in the acts of walking, standing, and maintaining the posture of the body. It functions, however, rather as a reflex center (a neurone group which transmits impulses from sensory to motor neurones) than as a center in which impulses originate, as is the case with the cerebrum.

14. Actions resulting from nervous processes originating within the cerebrum. A very large part of the activities of the body are thus fundamentally reflex actions; they do not require the aid of consciousness for their execution. And it is fortunate for us that this is the case; one has only to imagine a human being who has to give his attention, or "his mind," as we often say, to every adjustment of the



The parts of the nervous system represented are the cerebrum, cerebellum, bulb, and a segment of the spinal cord. Afferent nerves in red, efferent nerves in black. *m*, *m*, motor neurones to some of the muscles of the leg. These may be stimulated to coördinate action by neurones (*v*) from the cerebrum, neurones (*cb*) from the cerebellum, or by the afferent neurones (af^1) from the tendons, etc. In the bulb this afferent neurone connects with a second neurone (af^2), and this with a third (af^3), thus providing the path to the cerebrum and exciting in consciousness sensations of position of the leg (muscular sense). The same neurones connect with the cerebellum, as do also neurones from the inner ear. For further explanations see Chapter XV, pp. 309–335

PLATE D. Diagram of the nervous mechanism of walking

digestive, respiratory, and vascular systems required to meet the changing necessities of life; who has to keep his thoughts on every movement of walking or running; who has to be constantly on guard against loss of balance even when sitting still. Such a being is almost inconceivable; he would go crazy in a single day; but we can in this way realize to what extent the reflex mechanisms of the body perform the menial offices of life, leaving the mind free for higher things.

Speech is the result of movements in which the muscles of respiration, those of the larynx, those of the tongue, and those of the lips coöperate to produce articulate and intelligible sound. The act of writing also consists of a series of movements in which the muscles of the arm and hand cooperate to make thought visible; performing on a musical instrument, modeling in clay, carving wood or stone, casting bronze, or painting a picture, — all these things occur to us as examples of movements which are fundamentally neither reflex nor automatic. Such are the highest actions of the body, and the movements of which these actions are made up are chosen and directed by the will.

These higher actions, like consciousness, depend upon the presence of the fore-brain. When a certain area of the cerebrum is destroyed by disease, the power of speech is lost; when another part is destroyed, the skilled use of the hand is lost; destruction of other portions affects in the same way others of these skilled movements. In such cases locomotion, the maintenance of balance, the movements of respiration, and so forth may be and usually are unaffected; the patient merely loses the power of doing one or more of those things which involve the selection of disconnected and to some extent independent movements giving expression to some original thought, sentiment, or idea.

The neurones of the cerebrum and their connections thus constitute nervous mechanisms whose activity is essential to

consciousness, — to our seeing, our hearing, our smelling, and, more than this, to our understanding of what we see, or hear, or smell, — nervous mechanisms whose activity is also necessary to the expression of our thought in action. It is because of this fact that, when the cerebrum is removed, the animal becomes merely a complicated reflex machine, acting only as it is immediately stimulated from without or by events taking place within its own body.

15. Effects of anæsthetics on the nervous system. When a person passes under the influence of an anæsthetic, the first function to disappear is consciousness; the ether or the chloroform first paralyzes this highest and most complex connection between the afferent and the efferent sides of the nervous system. In this condition the patient may groan and struggle, for he is in somewhat the same state as the animal without cerebral hemispheres. The use of the surgeon's knife will still produce movements; respiration may be affected so as to result in groans or in movements which the inexpert observer, perhaps in alarm, attributes to severe suffering; and yet when the patient awakes he tells us he knew nothing of what passed and felt no pain. It is important to realize that *the signs of pain are not always reliable evidence of its existence.*

If the anæsthesia be pushed further, even these more complicated reflexes disappear. In the ordinary major operations of surgery the ether or the chloroform is given until it interrupts not only the cerebral connections between the afferent and efferent paths but also similar connections in the lower portions of the brain; it is even administered until only a few reflexes are left, such as the wink when the cornea is touched, the contraction of the pupil when the eye is exposed to light, and so forth — these serving as useful tests of the condition of the patient. If, for example, the pupil no longer contracts to light, it is an indication that

the anæsthesia is going too far — too near the point where the nervous mechanism of respiration and other vital processes will be paralyzed. The giving of the anæsthetic is then suspended until these reflexes are again well established.

After the operation, as the ether or chloroform is eliminated from the system, the reflexes return in the reverse order; and the unconscious movements, groans, incoherent, or even more or less coherent, talking (comparable with talking in one's sleep) are sometimes most harrowing to the feelings of those who do not understand that they are all unconscious acts. The physician and nurse who remain unmoved may even be wrongly charged with lack of feeling because they do not waste sympathy.

16. Inhibitory phenomena in the nervous system. We have learned that some nerves excite organs to activity, while others diminish activity or abolish it altogether (p. 188). The beat of the heart is quickened by one set of nerves and slowed by another; the circular muscle fibers of the arterioles are excited to contract by vasoconstrictor nerves, and their contraction is paralyzed or inhibited by vasodilators; many other examples might be drawn from the action of opposing neurones on various organs of the body.

Precisely the same thing is true in the brain and spinal cord. Afferent impulses may not only reflexly excite neurones to activity but may also inhibit the existing or threatened activity of other neurones, as when a sneeze is stopped by biting the upper lip or by pinching the nose; or an action may be inhibited by a volitional impulse from the cerebrum, as when the breathing movements are voluntarily stopped for a while, or when we consciously stop a wink or a sneeze. These are all examples of inhibition, not of the skeletal muscles concerned but of the neurones which innervate them — in other words, of the inhibition of one neurone by another.

It must be understood that inhibition is as essential a part of the activity of the nervous system as is excitation. Just as the driver of a team must urge on one horse while he restrains another, so in all more complicated actions, probably in all actions, reflex or volitional, the orderly movement is as much the result of holding one neurone in check as of stimulating another one to work, or to work harder. Consciousness proves its presence most conclusively by suppressing reflexes which would otherwise inevitably occur and by bringing about *new* movements to meet the desired end. Even in the highest processes of the most highly organized of nervous systems, namely, those in which human action originates, the man reveals his character and influences the world around him by what he does not do — by what he refrains from doing, sometimes at the cost of severe struggle against impulse, instinct, or passion — quite as much as by what he does. Education, even, has been partially defined as the "training of inhibitions and the control of reflexes."

17. The cerebrum the chief organ for the acquisition of new coördinations and associations. It would, however, be taking too narrow a view of the functions of the cerebrum to regard it simply as the seat of consciousness and volition. In Chapter VII, sect. 15, we saw that in addition to definite inherited reflex mechanisms, such as those of winking, — the so-called unconditioned reflexes, — new paths of conduction from the afferent to the efferent side are acquired during life by the repeated association of two acts. Doubtless all parts of the brain and spinal cord possess in some degree this power of making new associations like those concerned in the conditioned reflexes; but the cerebrum is certainly the organ in which they are made most readily, and there can be no doubt that one of its chief functions is the acquisition of such new paths of conduction as the experience

and activities of life "first blaze" within its nervous substance and subsequently, by the repeated passage of nervous impulses over the "blazed trail," change to "beaten paths" of easy conduction. Here every act and experience of life may leave its record, and here good and bad habits are acquired.

18. Use and disuse as factors in individual development, training, and efficiency. When we consider the marvelously complicated character of the nervous mechanisms which control our actions, we naturally wonder how this intricate machinery can be built and why it does not more frequently get out of order. We cannot say that a simple and comprehensive answer will not some day be given to these questions, but today we have no adequate answer whatever. The neurones with which we must work in life are born with us; but in most cases efficient connections must subsequently be made between them, thus perfecting the mechanisms they compose; and this perfecting of the nervous machine comes with use. The use of a nervous mechanism is generally essential to its proper development, just as the use of a muscle is essential to its strength. If the child never tried to walk, the neurones which carry out the movements of walking would not develop; not only would the muscles of an arm strapped down to the side of the body waste away and become practically bands of connective tissue, but the neurones concerned in the actions which the arms should execute would degenerate and might ultimately be irreparably injured.

Provision is made from earliest life for the proper development of these neurones, and the establishment of sensitive, responsive connections between them, by means of use; out of the first aimless movements of the head and eyes and hands and legs of the baby the simpler coördinating nervous mechanisms are one by one brought to perfection; then comes the training of those reflexes which

maintain the erect position and of those nervous mechanisms which govern locomotion; then *play* comes in, with its ceaseless activity, increasing still further the number of movements which the nervous system can make and correspondingly enlarging the possibility of human achievement. As the child grows older the family calls upon him to contribute some share to its life or support; new activities, in the shape of chores about the house or the farm, now share with play the development of the nervous system; activity becomes less general, more special. Finally the youth settles down to some definite occupation or pursuit, and the more strictly this is adhered to, the narrower becomes the range of activity; the more constantly a few systems of neurones are used, the more rarely are others called into play.

19. The physical basis of habits. All this indelibly writes its history in the nervous system. No fact is more significant or of greater physical and moral import than that the doing of any act so affects the connections of neurones with one another as to make it easier to do the same act again under the same conditions; that refraining from doing something toward which we are inclined similarly renders more easy the inhibitory processes concerned when the same conditions impel us again. We are largely what we make ourselves by the training which our actions give to the nervous system.

And what activity thus does for the *development* of power it does also for the *maintenance* of power. An efficient nervous mechanism of any kind, once acquired, does not remain efficient without use. The man who has developed a rugged constitution in colder climates and then lives for years in the tropics, constantly exposed to a warm climate, finds on return to the home of his youth that the mechanism of heat regulation does not readily adjust itself to cold damp winds and blizzards; the athlete who has learned to execute the

greatest variety of "tricks" in the gymnasium and then settles down to a sedentary life finds after some years that he is almost as helpless as the man who gave no attention to such training. It is unnecessary to multiply examples. Efficiency in any direction is the result of continued use of the mechanisms involved, and especially of continued training of the nervous system. As we fit ourselves to do some few things, and to do them well, we have not time to conserve by use the efficiency of all the nervous mechanisms we have acquired; we must to some extent sacrifice the more general activities for those which are more special and useful. But it must not be forgotten that this can be carried too far; that *a certain amount of general activity is a condition of healthy living*; and that one of the problems of life for us to solve, and to solve aright, is how to distribute our activity between the two. To the consideration of these questions we shall return in our study of personal hygiene.

CHAPTER XVI

TOBACCO, ALCOHOL, AND OTHER HABIT-FORMING DRUGS

We will now pass from the necessary foods and food accessories to the chemical compounds known as *drugs*, which act by changing the course of events within the body; and it is difficult to draw any sharp line of distinction between those which occasionally serve as medicine or stimulants and those of which daily use is made as food accessories.

Animals, as a rule, take substances into their bodies only to satisfy hunger or thirst, or other forms of appetite; man alone takes, in addition to his nutriment, food accessories and drugs for the sake of their special effects upon the nervous system or other organs. Many of the numerous food accessories which human ingenuity has discovered or devised are harmless enough in the form used, but others contain substances which are capable of poisoning the body. It is an important part of the study of personal hygiene to learn of what these substances consist, what is their action on the human organism, and wherein lie their special dangers.

1. The habitual use of drugs and similar substances. In a subsequent chapter reasons will be given for avoiding an undue dependence on drugs as a remedy for minor ills. It is a lamentable fact that large amounts of drugs and similar substances are swallowed by men and women, apart from any medical need requiring their use. Bad as is this practice, with its tendency to rely upon the uncertain action of a drug instead of taking proper hygienic care of the body, it is far worse to make habitual use of drugs for their special

effects upon the healthy body, for such habits are only too easily cultivated. There is no reason why a healthy human being, living a normal life amid healthful surroundings, should need to use drugs habitually; and a little consideration will show that the practice is dangerous.

2. The dangers in the habitual use of drugs. These dangers may be discussed under four subtitles, as follows:

1. *A drug is a thing foreign to the body.* When we eat meat or vegetables, or when we breathe air, we take into the body materials needed for normal living. These things have always formed part of the food of the human race and, unless wrongly taken, do good and not harm. When, on the other hand, we take a drug, such as chloroform, or cocaine, or opium, or alcohol, we take something which is foreign to the body, in so far as it has not been a regular constituent of human or animal food in the past. It is not needed, as protein and salt and water are needed; there is no special preparation for its reception; and while it may do good if administered by a doctor, there is grave danger that it may do harm if used habitually.

2. *Drugs produce imperfectly understood effects.* The exact action of many drugs is only imperfectly understood. In an emergency the physician uses them *temporarily*, for some effect which he desires to produce, thus tiding over a difficulty. He uses the drug only a few times, at most, and is consequently not greatly concerned about unfavorable attendant effects; it accomplishes some needed purpose, and if it does any harm, the organism may be trusted to recover from it. However, the *habitual* use of any drug is a very different matter. The very fact that it gives some new direction to the events taking place within the body means that abnormal conditions of life are being maintained, and we have already learned that abnormal conditions of life are apt to be unhygienic.

3. *Drugs not substitutes for hygienic living.* We are only too apt to substitute the use of drugs for proper living. We may, for example, take drugs to accomplish something which the healthy body should accomplish for itself without outside help. When one drinks a cup of black coffee to facilitate mental work which his fatigued condition would not otherwise allow him to do, he is trying to get from a drug the power which he should and probably could secure by normal sleep. The coffee acts on him as a whip on a tired horse; the same work is done as might have been done had the horse been allowed a little rest, but the horse is not as well off when he does the work under the lash as when he does it in a properly rested condition. Similarly, persons suffering from sleeplessness often take hypnotic drugs to produce sleep, and, superficially at least, the sleep thus secured resembles normal sleep; but experience shows that few if any hypnotics can be used for any length of time without bad effects. Here again a drug is being depended upon to do what the normal body should do for itself. Pepsin tablets may be taken to aid digestion, and thereby an attack of indigestion may sometimes be prevented or relieved; but a healthy stomach should furnish its own pepsin, and a stomach which does not do so is a sure warning that something is wrong in the conduct of life. It is irrational to neglect the duty of attending to the cause of the ailment, and it is foolish to substitute temporary relief for permanent cure. Perhaps if the drug did *all* that the proper care of the body does, *and did no more*, no serious objection could be made to its use; but there is probably no drug of which this is true, and for this reason it is foolish and rash to try to substitute the use of drugs for the hygienic conduct of life.

4. *Drugs tend to enslave the body.* If the drugs do not accomplish in the long run what should be done by the hygienic conduct of life, their extensive use becomes all

the more dangerous in view of the unquestioned fact that we are apt thereby to become their slaves. Every man is the slave, broadly speaking, of the habits he forms, and it is only a question as to whether he will be the willing slave of good habits or the abject slave of bad habits. The man who leads a hygienic life is the slave of muscular activity, of correct eating, of proper clothing, of rest, and of wholesome recreation; that is to say, these things become necessary to his life; he cannot get along without them. If for these proper agents of health he persistently substitutes some drug, whether it be alcohol, or tobacco, or coffee, or tea, or opium, the habit of using the drug is substituted for that of maintaining wholesome conditions. But since drugs cannot *entirely* take the place of such conditions, the constitution goes from bad to worse, and increasing dependence must be placed upon the drug. It is a safe rule that whenever we are uncomfortable or unhappy without the use of a certain drug we should cease using it until, with the help of hygienic living, we can get along without it.

There are people who are slaves of coffee, of tea, or of patent medicines, just as truly as there are slaves of tobacco, of alcohol, or of opium. It is worse to be the slave of alcohol than of coffee, because the evil consequences of alcohol are greater than those produced by the corresponding use of coffee; but it is by the same process in both cases that a man or a woman becomes a slave to the drug, and that process is the formation of bad habits.

With these practical considerations about the use of drugs — by which term it will be seen that we mean not simply the medicines purchased from the apothecary but all those substances which are taken into the body in order to give some new or abnormal direction to the course of events in the organism — we may pass on to the discussion of those in common use.

I. Tobacco

The use of tobacco by civilized peoples dates from the settlement of America by the Spaniards, having been learned from the Indians. Since that time it has spread over the entire surface of the earth and pervaded all ranks of society. By different persons it is variously regarded as a necessity, a luxury, or a curse. Tobacco habitués are not classed as drug addicts, although, as a matter of fact, they do habitually use a potent substance which has the characteristics of a drug.

3. The active principle of tobacco. Tobacco is the leaf of a certain species of plant. It contains an extremely active substance, called *nicotine*, which is strongly alkaline in reaction. On being heated, nicotine volatilizes, and hence is a constituent of tobacco smoke. When this active principle is introduced into the body, it produces changes (1) in the beating of the heart and in the circulation of the blood, (2) in respiration and the oxidative processes of the body, (3) in digestion and in the nutrition of the tissues, and (4) in the brain and in the nervous control of the whole mechanism. Repeated administration, however, leads to the development of a tolerance on the part of the organism, so that its effects largely diminish on habitual use.

4. The effects of tobacco. There is no doubt that the chief effects of tobacco are due to nicotine. But tobacco smoke and juice also contain some other substances which have a local irritant action, due to which reflex effects may be set up or injury be caused to the mucous membranes. The ill effects ascribed to tobacco are (1) disorders of the digestive system or capricious appetite frequently needing coaxing by tonics; (2) enlargement of the heart and irregularity in its action, called tobacco heart, in which changes in position and emotions produce a violent increase in rate;

and (3) impairment in nervous activity. It must be borne in mind that these effects are not shown, either collectively or individually, in every habitual user of tobacco. Their appearance depends partly on the duration of the habit and the quantity of tobacco used, but when any of the bad effects are shown the only cure is abstinence.

5. The habitual use of tobacco. Tobacco is a habit-forming substance, just as are tea and coffee. The effects are both quantitatively and qualitatively different in different persons. To no other material applies so well the maxim "one man's food may be another's poison." We may meet with one person of ninety years who has used it all his life without apparent harm, and another of twenty years who has wilted under its influence. These differences may be ascribed to differences in the physical and nervous constitution of the individuals, to the extent of the indulgence, and to the mode of living. There is no doubt that its excessive use is harmful, that it is more injurious to young than to mature persons, and that it is especially liable to harm indoor workers.

It is difficult to explain why tobacco has gained such a hold on the human race. Various explanations have been advanced, such as that it gives (1) a *sedative effect*, soothing the worried and resting the tired, and (2) a *stimulating effect*, quickening the mental faculties and whipping the physical into activity. As a matter of fact, the effects are different in the same person at different times, so that some investigators hold that it stimulates depressed functions but depresses excited ones.

6. Methods of using tobacco. Tobacco is used by different persons in different ways; it may be smoked, chewed, or snuffed. Each method requires a slightly different consideration.

1. *Smoking.* Pipes, cigarettes, and cigars are employed. Opinion is divided as to the comparative harmfulness of one

as compared with another. The cigarette is very commonly condemned, being vulgarly referred to as a "coffin nail." Its sale has been forbidden in several of the states. As a matter of fact, weight for weight of tobacco used, the cigarette yields less nicotine than either the pipe or the cigar. Combustion in the cigarette is more complete, so that most of the nicotine is destroyed, whereas pipes and cigars furnish almost ideal conditions for a large yield. Yet, on the other hand, the smoke of the cigarette is more frequently drawn deep down into the lungs (inhaled), consequently the absorption of nicotine is favored, and in the end as much is absorbed as would be from a pipe or cigar. Since young persons more commonly smoke cigarettes, and since it is to the young that tobacco is more harmful, it can be said that cigarettes injure a greater number of persons than do cigars and pipes. All forms of smoking lead to decrease in the acuteness of the senses of smell and taste and to irritation of the respiratory passages. In consequence of the latter, a chronic cough (worse in the morning) and vocal disturbances may make their appearance.

2. *Snuffing.* In snuffing, very finely divided tobacco is sniffed into the nose, usually from the palm or from between the thumb and index finger. The initial effect is sneezing. This is followed by a sensation of mild exhilaration, which is the effect craved by habitués. The amount of nicotine introduced into the system in snuffing is very small, so that the bad effects of the habit are due chiefly to the irritation of the lining membranes of the nostrils, which gives rise to disturbances in the sense of smell and hinders nasal breathing.

3. *Chewing.* For chewing, usually the stronger grades of tobacco are preferred. These are mixed with sugar, licorice, and other flavors, to suit the tastes of different persons. It is certain that a large amount of nicotine is placed in the

mouth and is dissolved in the oral fluids, but since most of the saliva formed in the process of chewing is expectorated, probably very little of the poison is retained in the system. Apart from the action of the nicotine, there are other ways in which chewing may be injurious; for instance, (1) by injuring the lining of the mouth, the gums, and the teeth, (2) by withdrawing from digestive use the saliva, which is so much needed to initiate digestion, and (3) by irritation of the stomach and decrease in the desire for food. It is quite noticeable that chewers are generally thin. One of the most objectionable features of chewing is the disposition of the ambeer, as the expectorated matter is called. One who chews is likely to become a promiscuous spitter, and hence a violator of both æsthetic and sanitary principles.

7. The hygienic aspect of the use of tobacco. Tobacco is often used without demonstrable bad effects when one is leading a hygienic life; but very often the habit, formed under these conditions, persists after the increasing intensity of occupation and the attendant cares and responsibilities of life result in neglect of muscular exercise and improperly directed nervous activity. As these begin to tell on the general health the unfavorable effects of tobacco become more noticeable.

1. The use of tobacco by those who have not attained their full growth is to be condemned. During youth nothing should be allowed to interfere with the best development of the heart and nervous system, and the use of tobacco endangers the proper development of both these most important parts of the human mechanism. It can hardly be doubted that many a young man has failed to make the most out of life because this habit contracted in youth has brought about a weakening of the foundations upon which he subsequently had to build, and, in consequence, he became stunted mentally and physically.

2. After one has reached maturity the case is different, and it becomes a matter of individual preference whether one shall, or shall not, use tobacco. Its moderate use by physically sound persons does not seem to be injurious.

II. Alcohol

In the case of an alcoholic drink we have to deal with something which, like tea, coffee, cocoa, and "temperance drinks," is used as a beverage, and to that extent must be classed in the same group. Alcoholic drinks are, however, taken as stimulants and so resemble tea and coffee; but they differ from these in their action upon the body. Moreover, their abuse not only is attended with bad hygienic effects, but also gives rise to degraded moral and social conditions. Everyone should be informed of their nature and of the dangers attending their use.

8. The alcoholic beverages. The alcoholic beverages are commonly spoken of as liquors. They are classified as (1) *malt liquors*, including beer and ale; (2) *wines*, such as hock, claret, Burgundy, sherry, and champagne; (3) *distilled liquors*, including brandy, whisky, rum, and gin; and (4) *liqueurs* and *cordials*. These groups are distinguished from one another largely by the method of preparation and by the amount of alcohol they contain. Malt liquors are fermented liquors which contain from 3 to 8 per cent of alcohol; wines also are fermented liquors, but contain from 7 to 20 per cent of alcohol; distilled liquors, on the other hand, are first fermented and then concentrated by distillation, and contain from 30 to 65 per cent of alcohol. In all these the most important constituent, so far as the physiological effects on the body are concerned, is the chemical compound known as ethyl alcohol (C_2H_6O, or C_2H_5OH). However, this can be depended on only when

the alcoholic beverages have been manufactured under the control of the government and are intended for medicinal purposes; we shall see presently that the greater portion of the liquor consumed is prepared illegally and may contain very dangerous poisons.

9. The physiological action of alcohol. Since ethyl alcohol is properly the important constituent of the alcoholic beverages, we will study first its effects on the body, and then, in future paragraphs, deal with the constituents of illicit liquors. Alcohol acts upon the human body in a number of ways, and its effects illustrate the various directions in which a single drug may work. Its different effects may be grouped under the subheads (1) *local action*, (2) *systemic action*, and (3) *food value*.

1. *Local action.* By local action we mean the changes which are produced at the point of contact of the substance with the body (for example, changes in the skin when it is rubbed thereon, or in the stomach when it is drunk). Among these may be mentioned its power to destroy disease-producing germs, its appetite-stimulating action in the mouth, and its reflex effects in increasing respiration and circulation.

2. *Systemic action.* This includes all the effects which follow absorption of alcohol into the blood stream. These are due almost entirely to changes in the central nervous system. The most important effect consists in an initial exhilaration, so that all faculties seem to be stimulated. This is accompanied by a flushing of the skin, a feeling of well-being, relief from fear and pain, and a sensation of warmth. If the quantity consumed has been considerable, in a short time there may follow a state of drunkenness, in which are exhibited in succession (1) wild excitement, during which irresponsible acts may be committed, (2) dull stupidity, with a lack of ability to control the mind or the

body, and (3) paralysis of the brain and muscles, so that the individual becomes helpless and may fall into the gutter or perish in a snowdrift. These successive symptoms display well-recognized stages in narcosis, and represent the action of a depressant of the alcohol type.

3. *Food value.* There has been much discussion as to whether alcohol is or is not a food; that is, whether it supplies energy to the body. Experiments show that it can be oxidized in the body more perfectly than any of the ordinary foods, approximately 95 per cent being burned down to carbon dioxide and water. Heat is thus yielded to the body, just as is done in the furnace by the burning of fuels. Whether alcohol can do more than supply temporary heat, — that is, whether it can also supply the power for muscular work, as do fats and carbohydrates, — we cannot in the present state of our knowledge positively say. Even though the oxidation of alcohol furnishes an easy source of heat production, since it is absorbed easily and without digestion, nevertheless it is a narcotic and therefore not a source of energy that can be used safely. The amounts which would be required to be of any considerable service as food are far greater than those in which it may be used with safety. In other words, in using alcohol for food one would be obtaining heat at the cost of direct injury to many organs and also at the cost of impaired working power. Moreover, men do not use alcohol as a food; they use it as a drug. Therefore, while the question as to whether or not alcohol is a food may be of physiological interest to the scientist in the study of the reactions of the human organism, this question is not a matter of practical importance.

10. Diseased conditions due to the use of alcohol. We have spoken of the physiological effects. Even under the direction of a physician these have proved so difficult to control that alcohol has been generally replaced in medicine by

other narcotics. When alcoholic beverages are used in immoderate amounts we have the sad and degrading spectacle of a drunken spree. Whether or not the drinker at first appears bright or witty, sooner or later there is presented the pitiable picture of complete loss of nervous coördination and control. The man becomes silly, or maudlin, or pugnacious, as the case may be, but always irrational; he staggers, stumbles, or falls, and finally passes into a drunken stupor. In this event the victim of his own indulgence is said to be "dead" drunk, or intoxicated, being, in fact, thoroughly *poisoned*. If such intoxication is frequently repeated, there is a complete breakdown of the nervous system; the victim of alcoholic indulgence may become a raving maniac and, with disordered vision and mind, may think he sees all about him snakes or foul vermin. The silly or foolish stage of this poisoning sometimes provokes smiles or laughter in thoughtless observers, but none can witness the more serious consequences of repeated intoxication by alcoholic drinks without disgust and horror.

Many steady drinkers, even though they have never been drunk in their lives, are apt ultimately to acquire various diseased conditions of the body, which we cannot consider here in detail. The heart may be injured, or the arteries become diseased; the repeated irritation of the stomach may produce chronic gastritis; or the connective tissue of the liver and kidneys may increase, thus crowding upon the living cells and ultimately throwing a large part of them entirely out of use. While it must not be supposed that drinking alcohol is the sole cause of these troubles, — for some or all of them may come from other causes, — the frequency of their occurrence in steady drinkers is suspiciously high, and this has led to the very strong conviction among medical men that alcohol plays a large rôle in producing them.

Furthermore, the habitual use of alcoholic beverages lowers the resistance of the body to the invasion of disease germs. As a result, steady drinkers are very susceptible to certain infectious diseases, particularly to pneumonia.

11. Summary of the action of alcohol as a drug. In small doses alcohol may be completely oxidized within the body without exerting any action as a drug. In the forms and amounts usually employed in alcoholic beverages it exerts, *in general*, a hypnotic or anæsthetic action; the effect on the system as a whole depends on the amount taken, and varies from the paralysis of inhibitory processes to the depression of all nervous functions, ending in drunken stupor. Repeated immoderate drinking may produce forms of temporary insanity, among which delirium tremens may be mentioned. There is, moreover, good reason for believing that steady drinking is very frequently an important agent in preparing the way for many other diseases, and is hence a serious menace to health.

12. Unwarranted excuses for using alcohol. Various pretexts are advanced for the occasional or habitual use of alcohol, such as a need for stimulation of the intellectual faculties, for increase in physical endurance, or for protection against cold. These will be discussed as follows:

1. *Is alcohol a stimulant?* Whether we shall call it a stimulant or not depends upon how we use that term. Some of the exhilarating effects of alcoholic drinks might lead us to speak of it in this way. People who have drunk wine often become more talkative, so that the first effects of intoxication often resemble those of stimulation. There is, however, strong reason for thinking that this action is only superficially, and not fundamentally, a case of stimulation, as we shall now see.

In studying the physiology of the nervous system we found that processes of *inhibition* are as important as are

those of *excitation*; and in mental operations the course of our thinking is constantly checked or inhibited by the knowledge of facts opposed to the conclusions toward which we are tending. *Probably it is this essential feature of all accurate and valuable mental work which is the first to be paralyzed by alcohol.* The man who takes alcohol becomes fluent, not because he is stimulated, but because of the removal of checks whose presence might make him talk less fluently, but which at the same time would make him speak and act more appropriately. He may become witty, and may say some brilliant things, but he will also, almost always, do and say some very erratic things.

Some cases of apparent stimulation are really due to the fact that alcohol, when taken in the form of wines and distilled liquors, sets up an irritation in the mucous membrane of the mouth, esophagus, and stomach, which *reflexly* excites the heart to greater activity or for the time being *reflexly* stimulates the nervous system. However, such stimulation is transient and, as the alcohol is absorbed into the blood, gives way to depression and even stupor.

It is neither possible nor necessary to state here in full the reasons which have led to the view, which seems to the authors erroneous, that alcohol in small doses is a stimulant and only in larger doses a depressant and hypnotic. Enough has been said to show that there are at least two opinions about the matter: that even if alcohol is at times a stimulant, it is an uncertain stimulant, and that its excitation is liable to give way at any time to depressing effects. A critical examination of the literature on the subject has failed to demonstrate to us a direct stimulating action of alcohol on the beat of the heart, respiration, digestion, or any of the functions. In sickness, medicines that are as effective and have no such element of danger as alcohol may be substituted, for the evidence indicates that any physio-

logical action of alcohol on the healthy body is depressive. This is notably true as to the beat of the heart, as to respiration, and as to the ability to do mental and muscular work.

We have dwelt at length upon this question in order to disabuse the student's mind of the idea that alcoholic drinks can be safely depended upon as an aid in the performance of work. Few causes are more effective in leading to the abuse of alcohol than the idea that when one finds difficulty in doing a thing it may be accomplished more easily by having recourse to beer or wine or whisky for their "stimulating" effect. In general, this is far from being the truth, and the person seeking such aid is really using a hypnotic and depressant. Obviously he would be acting more wisely to adopt other methods of accomplishing his end. Nor is this conclusion merely theoretical. Brain workers who know how to "keep a clear head" almost universally avoid alcoholic drinks.

2. *Does alcohol increase the ability to do muscular work?* That the general effect of alcoholic drinks is to depress rather than stimulate the powers of the body is furthermore indicated by the results of experiments on men doing heavy work, as, for example, soldiers on forced marches. In the Ashanti campaign the effect of alcohol as compared with beef tea was tested. To quote from Sir Lauder Brunton:

> It was found that when a ration of rum was served out, the soldier at first marched more briskly, but after about three miles had been traversed the effect of it seemed to be worn off, and then he lagged more than before. If a second ration were given, its effect was less marked, and wore off sooner than that of the first. A ration of beef tea, however, seemed to have as great a stimulating power as one of rum, and not to be followed by any secondary depression.

The results of these and other experiments lead us to the conclusion that alcohol cannot be depended upon to

increase the capacity for hard muscular work, and that in the great majority of cases it actually diminishes it.

3. *Does alcohol fortify the body against cold?* We have noted above that alcohol produces a flushing of the face and a sensation of warmth. These are due to dilation of the skin vessels, which brings a larger quantity of warm blood from the internal organs, with the result that the temperature of the skin rises and the person feels warmer. Because of this effect upon the cutaneous circulation, alcoholic drinks are frequently used by men exposed to cold, with the mistaken idea that the conditions within the body are thereby improved. The student has, however, learned (p. 227) that a *feeling* or *sensation* of warmth does not necessarily indicate greater heat production within the body; and he also knows that bringing the blood to the skin when the body is exposed to cold serves to increase the loss of heat. As a matter of fact the internal temperature often falls when alcohol is taken under these conditions. The story is told of some woodsmen who were overtaken by a severe snowstorm and had to spend the night away from camp; they had with them a bottle of whisky, and, chilled to the bone, some imbibed freely, while others refused to drink. Those who drank soon felt comfortable and went to sleep in their improvised shelter; those who did not drink felt very uncomfortable throughout the night and could get no sleep, but in the morning they were alive and able to struggle back to camp, while their companions who had used alcoholic drinks were found frozen to death. They had purchased relief from their unpleasant sensations of cold at the cost of lowering their body temperature below the safety point. This story relates, of course, an extreme case; but it accords with the universal experience of arctic travelers and of lumbermen and hunters in northern woods, that the use of alcohol during exposure to cold, although contribut-

ing greatly to one's comfort for the time being, is generally followed by undesirable or dangerous after effects.

13. The seat of the danger in alcoholic drink. The regular use of alcoholic beverages is dangerous for the same reason that the regular use of any drug is dangerous. We are too apt to rely upon the drug to do for us what we ought to accomplish only by the hygienic conduct of life; the drug never satisfactorily does the work, and we go from bad to worse, becoming its slaves. But there is certainly greater danger in hypnotic drugs, like alcohol, than in true stimulants, like coffee, cocoa, and tea. We need to have ourselves well under control when we use any drug; the highest faculties of the mind must keep tight rein or we may lose control of ourselves. With hypnotic drugs — to which class belong not only alcohol but ether, chloroform, opium, chloral, and other anæsthetics and soporifics — there is special danger that these powers of control (inhibition) may be stealthily paralyzed before we know it. Of course thousands of people use alcohol in moderation and never become drunkards; but thousands also, with no intention of imbibing immoderately, unconsciously let the reins drop, and before they know it the drug gets the better of them. Experience shows that it is with the hypnotic drugs that this most frequently happens.

Again, if we make a habit of taking alcoholic drinks, we are specially exposed to temptation from our fellow men to go too far. For the most part, people take coffee and tea or do not take them, as they please; no one urges them to use these drinks when they are disinclined to do so. To a less degree the same thing is true of tobacco, although here the force of fashion and example is stronger. But with alcoholic beverages the custom of "treating" makes the exercise of self-restraint more difficult than it would otherwise be, for here we are dealing with a drug which is

capable of *impairing self-control.* Someone treats a friend to a drink; the friend wishes to return the compliment, and so they drink again; the person with deficient self-control — and what little he has is now lessened — insists upon a third, and so on, perhaps to intoxication. This, of course, does not always happen; thousands are strong and escape the danger, but thousands are lacking in moral strength or do not know better, and many a week's wages has gone in this way, leaving behind poverty and misery and impaired manhood before the close of Saturday night.

14. Illicit liquors. While the Eighteenth Amendment to the Constitution was in force, alcoholic beverages could not be obtained legally in any part of the United States except on a physician's prescription. If the laws could have been enforced perfectly, only the sick would have been able to get alcohol in any form, and even they in only exceedingly limited amounts. This state of affairs did not suit many individuals who had already developed a craving for "drink"; they created a demand for it and to meet this demand illicit liquors, "moonshine" or "bootleg," were supplied by lawless persons, tempted by the chance of huge profits. Since the repeal of the Amendment in 1933, legal liquors may be obtained in a majority of the states, but this has not abated appreciably the flood of the illicit.

This unlawful liquor is prepared in the many varieties mentioned in a preceding paragraph. Some of it is genuine liquor which has been smuggled into the country or unlawfully diverted from medicinal uses, but most of it is only a poor imitation, manufactured under filthy conditions and from inferior materials. Ignorant or unscrupulous persons are concerned in making and selling it. Often, instead of producing the alcohol by fermentation and distillation, they concoct the liquors from water and very poisonous varieties of alcohol, adding flavors and coloring matter to simulate

the genuine. Even when the alcohol is made in the usual ways, the illicit liquors may be poisonous because of their having become contaminated with lead, arsenic, or alkalies, through the use of the wrong kinds of containers, during either manufacture or storage.

The poisons most frequently found are denatured alcohol, wood alcohol, lead, arsenic, and lye. Their poisonous effects will be briefly considered, as follows:

1. *Denatured alcohol* is ethyl alcohol to which certain substances have been added to render it unfit for beverage purposes. It is intended for use in manufacturing processes, such as the making of varnishes. When drunk, it may cause nausea, vomiting, pain in the abdomen, headache — and, sometimes, even death.

2. *Wood alcohol*, also called methyl alcohol, methylated spirit, or methanol, may quickly produce prolonged loss of consciousness, persistent paralysis, loss of eyesight, and also death.

3. *Lead* and *arsenic*, as found in liquors, give rise to chronic poisoning, which is characterized by pain in the limbs, disturbances in the movements, derangement of the mind, and violent colic in the case of the former and depleting diarrhea in the case of the latter.

4. *Lye* produces irritation and corrosion of the linings of the mouth, throat, and stomach, which give rise to inability to digest and assimilate the necessary food.

15. Concluding remarks on the use of alcoholic beverages. In the foregoing pages we have stated the salient facts concerning the physiological action of alcohol and alcoholic drinks. It only remains to remind the student of the obvious conclusions to be drawn from them and from the long and, on the whole, very sad experience of the race with alcoholic drinks. The first is that, except in sickness and under the advice of a physician, alcoholic drinks are wholly

unnecessary, and much more likely to prove harmful than beneficial. The second is that their frequent and especially their habitual use is attended with the gravest danger to the user, no matter how strong or self-controlled he may be. The third is that where legal liquors cannot be obtained and recourse is had to illicit varieties there is grave danger of severe poisoning from the adulterants.

It is true that history and romance and poetry contain many attractive allusions to wine and other alcoholic drinks, and it may also be true that such drinks, by loosening tongues and breaking down social, political, or other barriers (removing inhibitions), may tend toward conviviality and good-fellowship; but it is no less true that the path of history is strewn with human wreckage directly caused by alcohol; that many a promising career has been drowned in wine; and that indescribable misery follows in the trail of drunkenness. The only absolutely safe attitude toward alcoholic drinks is that of total abstinence from their use as beverages.

III. Other Habit-Forming Drugs

Although alcohol, tobacco, and even tea and coffee act like drugs or medicines and may be used in the treatment of disease, and although the habitual use of them by healthy persons is common, yet we do not ordinarily, in speaking of a drug fiend, mean a person who indulges in cigars, wines, or temperance beverages. In common parlance the drug habit means something more dangerous, more degrading, more soul-destroying. A stigma is implied and we almost shudder to touch elbows with a drug addict.

16. The drug traffic. The number of drug slaves is appalling — more than five thousand have been listed in some of the states, and in the country at large there are probably hundreds of thousands. About fifteen years ago our

government, recognizing the danger of the habit, passed the Antinarcotic Law, commonly called the Harrison Law, to regulate the sale of certain particularly pernicious drugs. It was hoped that this law would make it impossible to obtain such substances except for the treatment of the sick. The purpose of the law has, however, been fulfilled only in part, for there has sprung up an illicit traffic in the forbidden drugs, analogous to that referred to in the discussion of alcohol, and new victims are thereby being added day by day.

17. Dangerous habit-forming drugs. The most common habit-forming drugs (exclusive of alcohol, tobacco, and tea and coffee) are (1) opium and its derivatives, (2) cocaine, (3) certain headache medicines, and (4) certain soporifics. We will now consider the individual substances in each of these groups and point out the evil effects of their habitual use.

1. *Opium and its derivatives.* Opium is the dried juice of a species of poppy which is extensively cultivated in India and China. The chief characteristic of the action of opium is the depression of certain parts of the brain which normally enable us to keep the attention on an object or to maintain a line of thought. When it is eaten, or its smoke is inhaled, there is produced a pleasurable, dreamlike condition in which all worries and responsibilities are banished — fantasies alone fill the mind. From this state the individual passes into sleep, lasting perhaps for many hours. The dream state has passed away before he awakens, and there remains in its stead only a dull stupidity. Repetition of the use of opium rapidly leads to habit formation. The mind deteriorates, in a short time, so that it becomes unfit to cope with the duties and responsibilities of life. The will power is soon lost, and slavery to the drug is complete. In the more lucid moments between indulgences the victim

realizes his condition and desires to reform; but alas! he lacks the will power. But even should he attempt to break away from the habit, he will find that the terrible symptoms of abstinence make their appearance. These are partly mental and partly physical — the victim, whether awake or asleep, may have visions of poppy fields and hoards of opium, of opium tantalizingly dangling before his face, but just out of reach. His pulse and respiration increase with the expectation of gratification — and then the vision is gone. Gone! but only to return to plague him again. Sometimes there is a sensation of impending death, and frequently the victims at this crisis die or commit suicide. It is chiefly the fear of abstinence symptoms that keeps the addict chained to his destroyer, and this, together with the loss of will power, may impel him to pauperize his family, deny even food to his babies, or commit other crimes in order to renew his supply of the drug. Such persons can be cured and restored to usefulness, but only by being placed in institutions conducted especially for the purpose.

The important opium derivatives are *laudanum*, *morphine*, *heroin*, and *pantopon*. All of them produce the same general effects as opium. The tendency toward habit formation and the degradation of the mind is greatest in the case of heroin. This substance was so named because one of its effects is to exalt the *self* in its victims, so that they believe themselves to be generals or bosses, and hence frequently commit crimes in defense of their imagined positions. Congress has recently passed laws forbidding the manufacture and importation of this most dangerous and useless drug.

2. *Cocaine* is obtained from a plant native to the mountains of South America. When applied locally it is an anæsthetic, being used to prevent pain during surgical operations and the extraction of teeth. On being absorbed into the blood stream, it produces in some persons extreme depres-

sion, but in others marked stimulation which is later followed by depression. In the stage of stimulation both the intellectual and the physical faculties are quickened and the person can for a time accomplish things he could not before. Ultimately the mechanism, as it were, wears out, owing to its being run continuously in "high gear," and the addict becomes a hopeless cripple in mind and body. Sometimes the perceptive faculties are totally inverted, so that a caress is interpreted as a blow and friendship as hostility; the good in life is spurned, the evil cherished. As in the case of heroin, criminal deeds may be committed in defense of an exalted self. The treatment is difficult and must be institutional.

3. *The headache medicines.* Headache is a common complaint, which may be due to diseased conditions in various parts of the body, to defective vision, to overwork, or to unhygienic living. Drugs are often taken for its relief, regardless of the underlying cause. We have previously noted that drugs do not ordinarily cure, but instead merely relieve a symptom. This is true in the case of headaches, for only the pain is relieved, while its cause (indigestion, or whatever it may be) continues to operate. Hence, as soon as the effect of the drug wears off, the pain returns, and this in turn calls for a repetition of the medicine — and so on, ad infinitum.

Hence we have here the case of a habit being formed in a peculiar way. The only sensation gotten from a headache medicine is absence of the pain. There is no pleasurable effect as with opium. The most commonly used are acetanilide, amidopyrine, antipyrine, aspirin, phenacetin, and the proprietary or "patent" medicines made from them. The last are too numerous to be mentioned by name, but each of them is required by the Pure Food and Drugs Act to have printed on the label of the container the name of the drug of which each is made. By keeping this in mind, the

student may readily determine that acetanilide is the one commonly dispensed at the soda fountains.

All the above medicines produce practically the same effects — relief of the headache, lowering of temperature in fevers, and diminution of the ability of the blood to carry oxygen. On account of the last-named effect, nutrition is interfered with, respiration is quickened, and the work of the heart is increased. Habitual use of these medicines leads to faintness, thinness, and cardiac weakness. Recently, many cases of severe collapse and sudden death have been reported after amidopyrine, due to a rapid and profound destruction of the white corpuscles. Physicians exercise great caution in using this drug; laymen are warned not to employ it at all in self-medication, since they cannot safeguard themselves against the toxic effects.

4. *The soporifics.* Soporifics are drugs which are employed to induce sleep. They do this by depressing brain action just enough to render the person drowsy. Sometimes alcohol or opium is used, but more frequently certain drugs which are employed only to produce sleep. Among these may be mentioned chloral hydrate and veronal (or barbital). The former manifests actions similar to those described for alcohol, but it has no food value and, on repeated use, damages the heart. Addiction to it leads to mental and physical deterioration. Veronal also acts by depressing brain action, and its habitual use causes destructive changes in the liver, which lead to defective nutrition, to loss of weight, and to weakness. The student should bear in mind that the root of the evil, in the case of the soporifics as in that of almost every other drug, lies in the substitution of a drug for normal habits of wholesome living. This may be done for a time without apparent effect on the organism, but in the end nature always exacts a penalty for the performance of a physiological action in an abnormal manner.

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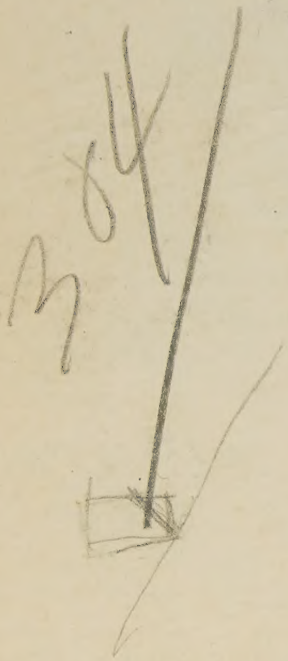
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